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Energy-Efficient Housing Construction

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Canada Mortgage and Housing Corporation, the Federal Government's housing agency, is responsible for administering the National Housing Act.

This legislation is designed to aid in the improvement of housing and living conditions in Canada. As a result, the Corporation has interests in all aspects of housing and urban growth and development.

Under Part V of this Act, the Government of Canada provides funds to CMHC to conduct research into the social, economic and technical aspects of housing and related fields, and to undertake the publishing and distribution of the results of this research. CMHC therefore has a statutory responsibility to make widely available, information which may be useful in the improvement of housing and living conditions.

This publication is one of the many items of information published by CMHC with the assistance of federal funds.

Energy-Efficient Housing Construction

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La construction de maisons efficaces au plan énérgetique (EPÉ)

Canada Mortgage and Housing Corporation
Société canadienne d'hypothèques et de logement

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Preface

Energy-efficient houses have been on the market in Canada for several years. Recently, however, better design and construction technologies have created a new generation of efficient homes. The energy performance of these dwellings surpasses that of their "energy-efficient" predecessors. As a result, the new houses have been described using such terms as "super energy-efficient" and "super-insulated". In this book, the simple term energy-efficient (EE) is retained — but it should be understood to refer to the new generation of highly efficient houses.

This publication is intended to serve as a basic introduction to the principles and practices employed in recent EE construction. It is also designed to complement and supplement the CMHC slide-tape show *Envelope Construction of Energy-Efficient Housing**. **However, this book is not a comprehensive treatment of EE house construction: the text assumes that the reader is already familiar with conventional building practices and so dwells primarily on the features that make EE housing unique.**

This book focuses on construction as practiced in small residential buildings below four storeys and below six hundred square metres of floorspace. Various ideas and techniques are presented to assist those who are seeking new ways to conserve energy in such buildings. Although the measures discussed are new and still evolving, all have been implemented.

They are generally easy to utilize, but do often entail complex physical concepts that may require extensive knowledge to manipulate. **Thus, the reader should assume total responsibility for implementing any of the ideas presented here, and should consider seeking professional advice before so doing.**

This book is divided into two major parts. Part I covers the principles of energy-efficient housing, whereas Part II explains construction details for each of the major elements of the house. The text is extensively illustrated but, for the sake of clarity, technical details unrelated to the particular EE construction feature under discussion may be omitted from the drawings. Where necessary, the drawings have been slightly modified to clearly show the position of the air-vapour barrier.

* Ottawa: Canada Mortgage and Housing Corporation, March 1982.

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Part I

Energy-Efficient Housing: The Basics

Chapter 1 Introduction
Chapter 2 The Principles of EE Housing

Chapter 1

Introduction

The Future — Energy and Housing

The houses being constructed today have, for the most part, a life expectancy extending well into the twenty-first century. Owners of these houses are likely to be subjected to energy supply problems and large energy price increases. Clearly, the construction of houses that are as energy-efficient as possible makes good, long-term sense. Stringent energy conservation measures are becoming increasingly desirable in new house construction.

What does this mean for the housing industry?

It means that the energy-efficient house is here to stay. Such houses can be expected to gradually assume an increasing share of the market, until practically all new housing starts are energy-efficient.

It means that more and more housebuyers are going to be concerned about their homes' monthly PITE payments (principal, interest, taxes, and energy) rather than just the traditional PIT (principal, interest, and taxes) payments. Energy-efficiency will become a desirable feature.

It means that the housing industry will be exposed to a rapid evolutionary change. It will encounter new building techniques, new types of hardware, new materials, new codes, new testing procedures, and new inspection requirements.

It means that those home builders who do not adjust will be operating at a disadvantage.

It means, above all, that firms and individuals in the housing industry have a major opportunity to become involved in the early development of what promises to be a major growth sector: construction of energy-efficient houses.

Canada is a world leader in the development of a new generation of highly energy-efficient (EE) housing technologies. A number of pioneering projects across the country have produced houses that are built to such high standards of thermal efficiency that they hardly need any kind of space-heating system.

These highly energy-efficient dwellings are not merely standard houses with a few added energy-saving features; they are something new, representing an evolution of traditional building practices. Even so, the energy-efficient house **looks** like a standard house. Most of the differences are hidden within the structure. Even there, the differences are not as dramatic as might be expected: EE techniques are new, but they are nevertheless extensions of current practice.

The transition to the construction of highly energy-efficient housing will require some effort, including, for instance, training programs and the adaptation of established house designs. However, it is important to realize that EE housing depends upon the same trades, and many of the same skills, as traditional housing. The builders of conventional homes **can** build EE homes — and in fact many are already doing so. The transition to energy-efficiency need not be difficult.

The Benefits of EE Housing

The highly energy-efficient house is more expensive to build than a conventional house. Compared with a house built to 1975 standards, the extra cost for a single family dwelling is typically in the range of $3500 to $7000 (1982 prices).

The cost of space-heating a house varies across Canada, according to local climate, local building practice, and local fuel costs. However, most of Canada's housing stock has an annual space-heating bill somewhere in the range of $500 to $1500, based on 1981 prices. In an energy-efficient house the space heating bill can be reduced to as little as one-fifth of the normal level, giving annual fuel-cost savings in the range of $400 to $1200.

For the home buyer, is an investment in EE housing financially worthwhile? A number of factors must be considered:

EE houses may have higher initial PITE (principal, interest, taxes, and energy) payments than houses built to 1975 standards. However, over the years the PITE payments will be likely to rise more rapidly in the 1975 house than in the EE house, since energy costs can be expected to inflate rapidly.

The resale value of the EE features of the house can be expected to increase (in the same way that other features of a house appreciate in value). The extent of this increase is hard to predict, but Canada's energy supply and pricing situation suggest that a home's energy-efficiency will become an attractive, and hence valuable, asset.

The cost of achieving energy-efficiency in **new** construction is normally much less than the cost of upgrading an inefficient house years **after** its construction. If a home is likely to be retrofitted for energy conservation in the future, it is sensible to avoid the extra expense by building an efficient house in the first place.

In short, the relative costs and benefits will be different for each EE house built.

Costs and benefits fluctuate depending on the availability and cost of energy, interest rates, and the cost of materials and labour. For this reason, the costs and benefits should be evaluated carefully if cost effectiveness is the primary reason for adopting EE measures.

Dollar savings are not the only attraction of EE housing. Builders are discovering that many homeowners view energy efficiency as a protection against the worst effects of an uncertain energy future. These homeowners are willing to pay for such security. In addition, the EE house is a comfortable house, with few drafts, no cold walls, healthy humidity levels, reduced noise levels, and cool summer temperatures. To the home buyer who values comfort, energy-efficient construction is an attractive feature.

Chapter 2

The Principles of EE Housing

The Basic Objectives

In designing an energy-efficient house, the basic aim is to reduce annual heat **losses** to such a low level that most of the remaining space heating requirements can be met by what is known as "internal heat gains". These gains are the heat sources present in every home: electrical appliances, lighting, people, and sunlight shining through the windows ("passive solar gain").

Internal gains supply nearly half of the heat required by a relatively well-insulated conventional home (see Figure 1). If this total heat requirement can be cut in half, therefore, the internal gains will then be sufficient to cover most of the remaining need. This is, in fact, what an EE house does: the heat loss through the structure is about half of that in a conventional house. As a result, the amount of energy used by the heating system falls to as little as a tenth of normal levels. In some energy-efficient designs, the demand for supplementary heat may be so low that a furnace becomes unnecessary.

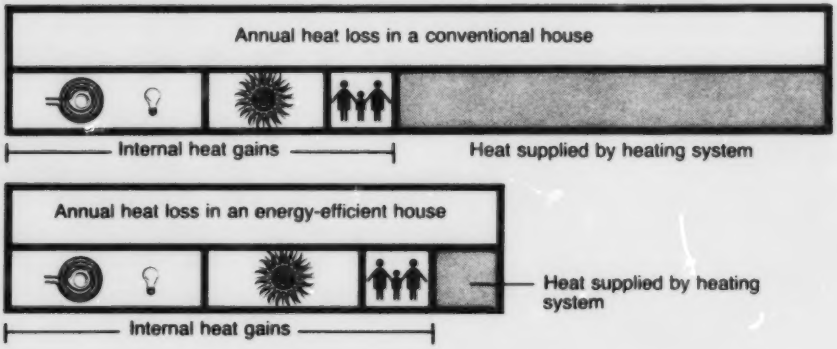
Annual heat loss in a conventional house
Internal heat gains
Heat supplied by heating system
Annual heat loss in an energy-efficient house
Heat supplied by heating system
Internal heat gains

Figure 1. Comparison of approximate heat loss and heat gain in conventional versus EE housing

EE house construction does not focus exclusively on cutting heat losses. Internal gains are also augmented where possible, essentially through a modest effort to increase passive solar gain. Notwithstanding such measures, the major pre-occupation in energy-efficient housing remains the "loss" side of the energy equation.

Moisture in Houses

Before considering the specific features that are used to reduce heat loss in EE houses, it is important to have an understanding of the possible problems associated with moisture in buildings. These problems are shared, to a greater or lesser degree, by all types of houses. EE houses are not exempt; indeed, without proper attention to design details, the moisture problems may be aggravated.

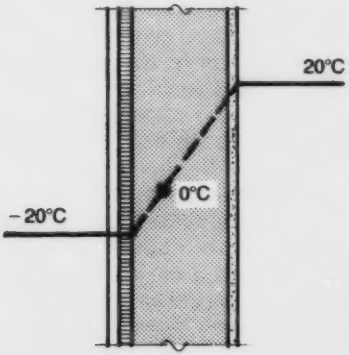

Figure 2. Condensation in walls

The Problem

In a typical household, 9-14 kg of water vapour are generated daily by the combined effects of respiration, cooking, laundering, and bathing. Most of this moisture, however, eventually escapes to the outdoors. Three escape mechanisms are of major importance:

1. In many houses a great deal of moist indoor air is exhausted up the flues and chimney(s) serving the furnace, fireplace, or woodstove.
2. In most homes, a great deal of warm indoor air seeps out of the house through various cracks and holes, carrying water vapour with it.
3. Finally, water vapour escapes from houses by diffusing through building materials (such as drywall and wood).

Moisture escaping by the second and third of these mechanisms does not necessarily disappear without a trace. As air and moisture pass from the heated interior to the unheated exterior of a house, cooling takes place. Since cold air is able to hold less moisture than warm air, this cooling may result in **condensation within** the walls or attic of the house (see Figure 2).

Water that condenses in a building's structure can cause any insulation present to lose its effectiveness (since water is a good heat conductor and since some types of insulation compact when wet). If the insulated space is not vented, moisture can also cause rotting, paint peeling, mold growth, and lead to structural damage.

Conventional Houses

In older conventional houses, a number of factors have generally prevented such moisture damage. The most deliberate of these factors is the vapour barrier normally installed during house construction. Though such barriers reduce vapour diffusion into walls and attics, they do little to control condensation associated with air leakage and are, as such, of limited effectiveness. Better protection has been provided by a number of other factors that are, by and large, the inadvertent by-products of energy-inefficient construction.

The first of these factors results from the action of the furnace (or of some other combustion heating system, such as a woodstove). As noted above, indoor air is exhausted up the flue(s) serving these devices. Such losses occur at all times, but are greatest when the furnace is operating. Hot flue gases rise quickly up the chimney and create a strong draft that draws air from the rest of the house. This lost air is, in turn, gradually replenished by outside air drawn inwards through the house envelope. This action of the furnace thus tends to counteract the outward flow of humid air into the attic and walls. Since the furnace will operate a great deal in energy- inefficient houses, the possibility of moisture problems is significantly reduced in such dwellings.

Other factors also have helped protect conventional houses. For instance, because they are so leaky, the indoor air in these buildings tends to be dry. The drier air is, the colder it must become before condensation takes place. In any case, limited amounts of condensation are quite tolerable, since the moisture will slowly revapourize and gradually escape to the outside (especially on warm days). This process is most evident in ventilated attics.

Collectively, these factors have, in the past, reduced the incidence of moisture damage. However, as electric heating and increased insulation levels have become more widespread in **conventional** housing, more cases of moisture damage have been observed.

Energy-Efficient Houses

Many of the factors that have protected conventional houses are, as mentioned earlier, the somewhat inadvertent side-effects of energy-inefficient construction. The energy-efficient house is, therefore, potentially vulnerable to condensation problems, since it will not "benefit" from such side-effects. For instance, the furnaces in EE houses will not be heavily used and, in the case of some heating systems, may not require draft air. This means that the furnace will not effectively counteract the outward flow of humid air. Futhermore, since uncontrolled air change is greatly reduced in EE houses, indoor humidity levels will be higher (and more comfortable) than in conventional houses.

These changes increase the likelihood of condensation in the structure of EE houses. Consequently, careful control measures must be taken in order to effectively seal moisture inside the house. The standard vapour barrier simply will not do the job.

Two types of measure are required. First, improved installation of the vapour barrier will help prevent vapour **diffusion** into the walls and attic. Second, an air barrier must be installed, to prevent **air leakage** into the shell.

In current practice, it has been found that the two functions — vapour barrier and air barrier — can be readily combined in a single air-vapour barrier that is effectively impermeable and virtually airtight. This type of barrier has become one of the essential elements of current EE house construction, and as such is discussed in detail in the next sections.

EE Housing: The Main Principles

The design and construction of energy-efficient houses should be guided by four main principles:

1. High levels of insulation.
2. Airtight construction.
3. Controlled air management.
4. Passive solar design.

Each of these principles plays a key role in the EE house; each is discussed, in turn, in the following pages. In implementing these principles, it is essential that the highest standards of workmanship be maintained. Otherwise, the full advantages of EE construction will not be achieved.

Principle 1: High Levels of Insulation

Energy-efficient houses are built with very high levels of insulation wrapping the entire house. Table 1 divides Canada into three zones and presents suggested minimum insulation values for each. These zones are based upon a type of climatic data known as heating

	Zone A Up to 3 500 Degree Days	Zone B Up to 5 000 Degree Days	Zone C Up to 6 500 Degree Days
1. Ceilings (including cathedral ceilings)	RSI 7.8	RSI 9.3	RSI 10.6
2. Walls	RSI 5.1	RSI 6.0	RSI 6.9
3. Foundation Walls (where 50% or more is below grade)	RSI 2.2	RSI 3.0	RSI 3.9
4. Exposed Floors Crawl Spaces	RSI 4.7	RSI 4.7	RSI 4.7
5. Slabs on Grade	RSI 2.2	RSI 3.0	RSI 3.9
6. Basement Floors	RSI 1.3	RSI 1.5	RSI 1.8

Note 1: RSI 1 = R 5.679

Note 2: The insulation values in Table 1 differ from those recommended by *Measures for Energy Conservation* 1983 (Ottawa: NRCC), which calculated insulation levels based on these energy prices: oil — 15¢/litre, gas — 20¢/m^3, electricity — 3.5¢/kwh. Because prices are considerably higher in some parts of Canada, Table 1 uses an adjustment factor of 1.6 over the levels in *Measures for Energy Conservation*.

Table 1. Appropriate Energy-Efficient Insulation Levels

degree days. The longer and colder the heating season, the greater is the annual number of degree days and so the higher the recommended insulation levels. Figure 3 is a degree day map of Canada.

The RSI* values called for in Table 1 require a considerable thickness of insulation. In walls, this can be achieved only by increasing the wall thickness well beyond its traditional 89 mm.A number of multilayer wall designs have been developed, some of which are still in the process of refinement. The variations include double-frame walls, strapped (or furred) walls, and the use of rigid insulation sheathing. In a number of designs the 140 mm stud frame replaces the 89 mm stud frame.

* RSI values are used to indicate the thermal resistance of materials, with a higher RSI value indicating a higher level of insulation. RSI values are the metric equivalent of the imperial R-value. RSI 1 = R 5.679.

The worst areas of heat loss in a wall usually occur at the top and bottom plates and around floor headers, where there is usually a large amount of solid wood which has relatively poor insulation properties. The energy-efficient house pays special attention to these areas.

Increased insulation levels in other parts of the house require less fundamental change in building practices, though a number of special problem-solving techniques have been developed. These, and the details of wall design, are discussed in Part II.

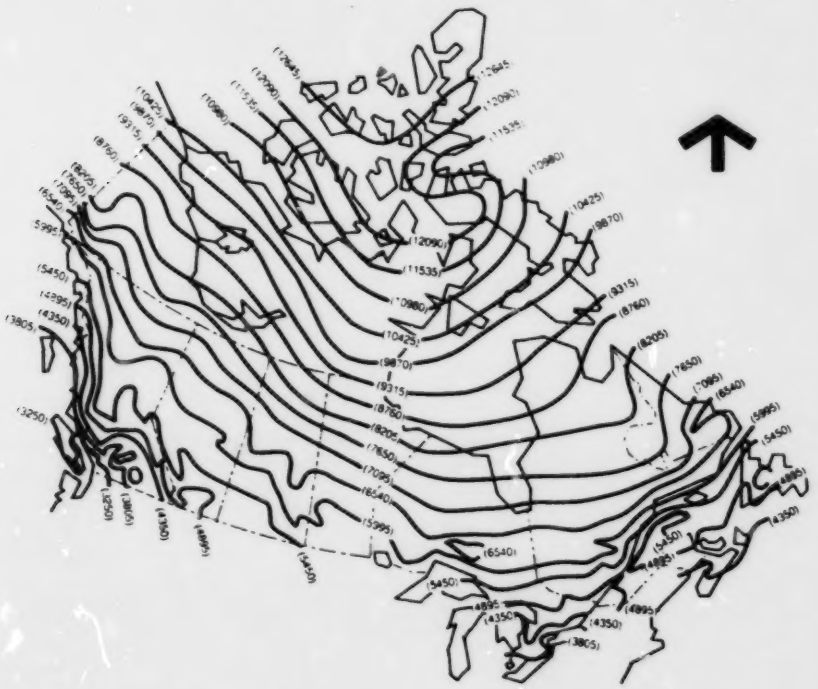

Figure 3. Annual degree days below 18°C

Principle 2: Airtight Construction

Any house has a large number of potential air leakage points, as indicated in Figure 4. These leakage points let cold outside air in, and warm inside air out. As a result, in a conventional house, it is not uncommon for the heated indoor air to be completely changed every half hour. A major potential problem associated with this air change — condensation in the building's structure — has already been discussed. There is, in addition, a second problem: such air change typically accounts for 25-30 per cent of the total house heat loss (and more if the leaky house is well insulated).

The use of an air-vapour barrier is an attempt to prevent these problems by stopping virtually all air leakage. In addition, as noted previously, the barrier blocks vapour diffusion **through** building materials into the house structure.

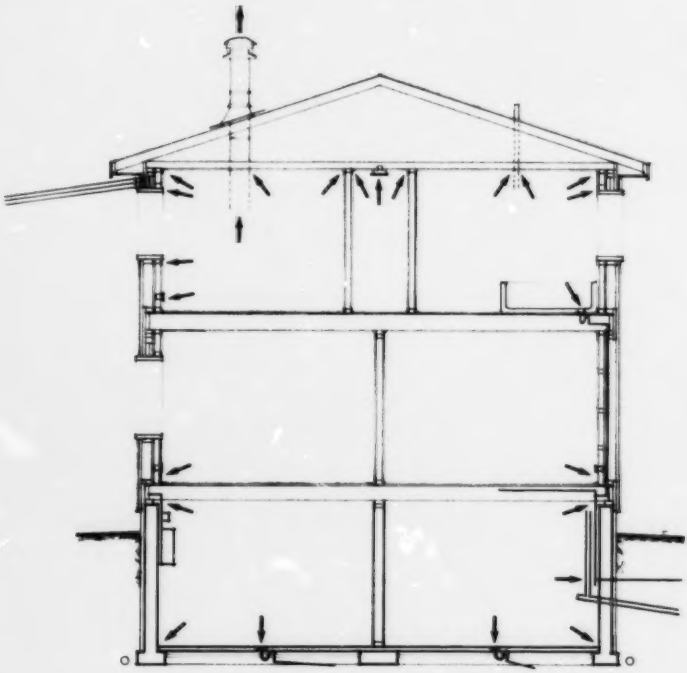

Figure 4. Points where infiltration and exfiltration can occur

Extra large sheets of 0.150 mm polyethylene are normally used.* In order to provide an almost perfect airtight envelope around the house, the various sections of polyethylene are carefully joined and sealed to each other. All points where the air-vapour barrier terminates around windows, doors, vent stacks, chimneys, and so on are also sealed. Furthermore, doors, windows, and other openings through the barrier are themselves constructed so as to control air leakage.

The techniques used to achieve this continuous barrier are discussed in detail in Part II. They represent a key aspect of EE housing construction.

To ensure that satisfactory airtightness has been achieved, techniques are available to measure the relative infiltration rate of individual houses. These techniques involve the use of blowers which depressurize the house, thereby exaggerating the natural infiltration rate. Such testing provides a valuable quality-control mechanism.

Principle 3: Controlled Air Management

Because EE houses are built to be airtight, the indoor air supply must be controlled in three ways.

First, air quality must be maintained. Apart from water vapour and the obvious kitchen and bathroom odours, a variety of pollutants are routinely added to the air, including: aerosols and vapour from cleaning materials and other household chemicals; contaminants generated by tobacco smoking; gases associated with some new materials being used in the manufacture of furniture, carpets, and fabrics; and radon gas seeping into basements from the surrounding soil.

A supply of fresh air is therefore necessary to maintain indoor air quality. In a conventional "leaky" house, where the inside air may change completely every half hour, fresh air is readily available. This "ventilation" is uncontrolled and, in fact, uncontrollable. The result is relatively clean but overly dry air, and excessive heat loss.

In an energy-efficient house, the natural rate of air change is much lower. Typically, several hours would be required to complete one change. This is not a high enough rate to prevent excessive buildup of moisture, pollutants, and odours.

The solution, therefore, is the provision of additional **controlled** ventilation. There are several specific ways of achieving this, but the basic approach is straightforward. Stale house air is exhausted through one vent, and fresh air is drawn in through a second vent. Heat loss is minimized in two ways: first by maintaining the minimum acceptable ventilation rate; and second, by possibly incorporating a heat exchanger to recover heat from the exhausted house air. Heat exchangers for this purpose are now becoming increasingly available.

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* Note, however, the footnote to Worksheet A in Part II of this book.

Details concerning indoor ventilation are supplied in Part II, Chapter 9.

A second air management concern is the need to provide combustion and draft air for furnaces and other fuel-burning heating systems (including water heaters and wood stoves).

As noted previously, in a conventional house the required air is simply drawn from within the building. This results in what is referred to as "negative pressurization": the loss of air creates a partial vacuum inside the house. This gentle vacuum in turn draws outside air into the home through the many leaks in the building's envelope. Thus, the air lost up the chimney is easily replaced (although the building normally remains at a slightly negative pressure relative to the outside). The net result is that the heating system has a ready and adequate supply of air.

In an airtight house, on the other hand, combustion and draft air cannot be replaced by the natural infiltration of outside air (since there is minimal or no natural infiltration). Therefore, in order to avoid hazardous back draft situations, a fuel- burning heating system may require its own separate air supply, isolated from the house air supply and ventilation system. Methods for achieving this are available, and are outlined in Part II, Chapter 10.

The third concern related to air management is the possibility of **positive** pressurization of the house relative to the outside. Due to such factors as wind effects on the inlet and outlet vents, the ventilation system previously described can in some cases induce a positive pressure. In many conventional homes, such an effect would be counteracted by the action of the furnace (which, as noted above, tends to induce a negative pressure). In an EE house, however, this would not normally be the case. Any heating system that required significant quantities of combustion and draft air would be provided with its own supply — and so would not draw air from the house.

Positive pressurization is undesirable, since it can have the effect of "squeezing" warm, moist, indoor air into the building envelope. Condensation and the associated moisture problems can result, damaging the building's structure. Accordingly, special measures must be taken to provide negative pressurization in EE houses. The nature of these measures will depend upon the choice of heating system. The range of options is outlined in Part II, Chapter 10.

Principle 4: Passive Solar Design

Apart from the efforts to cut heat loss, energy-efficient house design concentrates on optimizing passive solar gain. Sunshine entering through south-facing windows is the essence of passive solar gain. Therefore, EE houses are, if possible, oriented to maximize their unobstructed southern exposure in winter, and the building's windows are concentrated on the south side. In other words, an EE house does not normally have more windows than a conventional house — the windows are simply relocated. This is a cost-free measure; nevertheless, passive gain can supply 30 per cent or more of the heating load of an EE house.

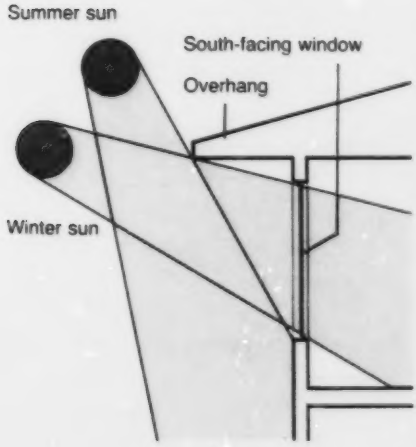


Figure 5. Use of overhang to limit summer sunshine into house

In principle, it is possible not only to concentrate windows on the south side, but also to increase the total window area beyond the level typically found in a conventional home. If this is done, however, additional "thermal mass" **must** be provided to store the extra solar heat that would be collected. If sufficient mass is not provided, the house will be subject to large temperature swings. Given the additional cost of thermal mass, and given the fact that uninsulated windows are heat losers when the sun is not shining, the total window area in EE houses is generally held to conventional levels.

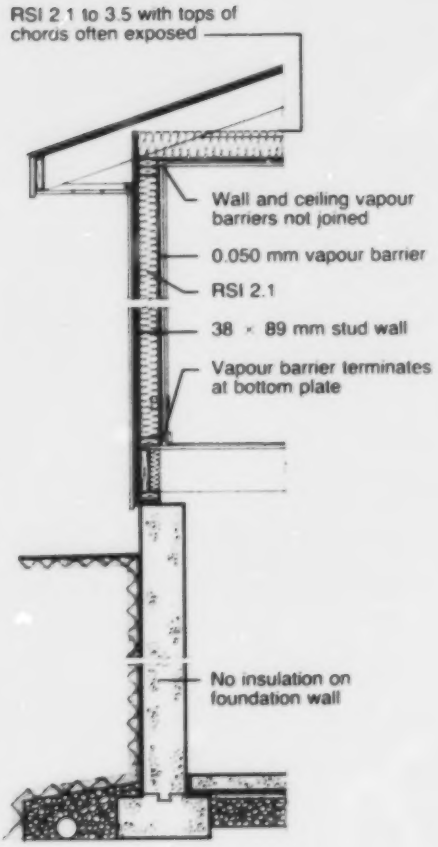
It must be remembered that passive solar gain is not confined to the winter months. If not shaded, the summer sun can cause overheating in any home, but more so in a passive solar home. Therefore, protection such as a retractable awning, a movable overhang, or deciduous trees must be provided. Alternatively, a fixed overhang can be provided, with its dimensions taking advantage of the fact that the summer sun is higher in the sky than the winter sun (see Figure 5).

Details about windows and passive solar are discussed in Part II, Chapter 7.

A Comparison

By way of summary, Figure 6 compares some of the features of energy-efficient houses with two more conventional houses. The "typical 1975" house is the familiar "base case" — a starting point for energy-efficiency improvements. The 1978 "typical Measures" house is based on the National Research Council publication, *Measures for Energy Conservation in New Buildings 1978*, which recommends a series of minimum standards for energy-efficient housing.* This house represents a considerable improvement over the 1975 standard design, but there is no significant improvement in such areas as the method of vapour barrier construction.

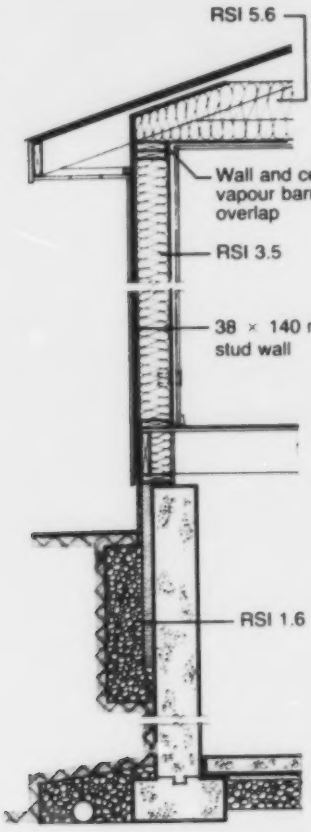
As has been described, the EE house provides further and major increases in insulation; improved airtightness; a controlled air management system; and greater attention to passive solar design. It is evident, at a glance, that energy-efficient housing involves a significant improvement over traditional building practices — and can provide a significant efficiency improvement even when compared to the 1978 "Measures" house.


RSI 2.1 to 3.5 with tops of chords often exposed
Wall and ceiling vapour barriers not joined
0.050 mm vapour barrier
RSI 2.1
38 × 89 mm stud wall
Vapour barrier terminates at bottom plate
No insulation on foundation wall

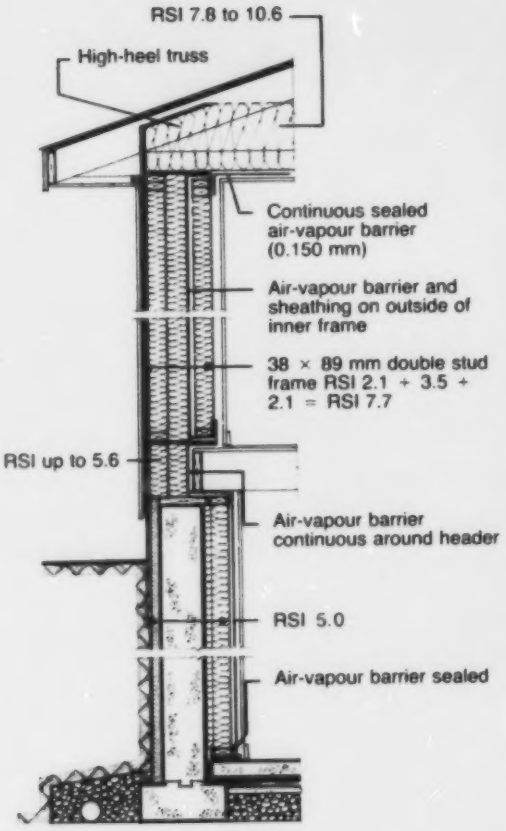
A STANDARD CONSTRUCTION (typical 1975)

Figure 6. Comparison of various housing types

* Associate Committee on the National Building Code, *Measures for Energy Conservation in New Buildings 1978*. NRCC No. 16574. (Ottawa: National Research Council, 1978.) See also: *Energy Conservation in New Small Residential Buildings*. NHA 5417.(Ottawa: Canada Mortgage and Housing Corporation, 1981.)



B TYPICAL "MEASURES" CONSTRUCTION


RSI 7.8 to 10.6
High-heel truss
Continuous sealed air-vapour barrier (0.150 mm)
Air-vapour barrier and sheathing on outside of inner frame
38 × 89 mm double stud frame RSI 2.1 + 3.5 + 2.1 = RSI 7.7
RSI up to 5.6
Air-vapour barrier continuous around header
RSI 5.0
Air-vapour barrier sealed

C EXAMPLE EE HOUSE

Part II

The Techniques of Energy-Efficient House Construction

Chapter 1 Introduction
Chapter 2 Air-Vapour Barriers
Chapter 3 Foundations
Chapter 4 Headers
Chapter 5 Walls
Chapter 6 Ceilings
Chapter 7 Windows
Chapter 8 Doors
Chapter 9 Air Management: Indoor Ventilation
Chapter 10 Air Management: Other Aspects

Chapter 1

Introduction

Part II discusses the more important construction details for energy-efficient houses, especially the placement of insulation and the installation of the air-vapour barrier. This book does **not** consider such topics as framing, nailing, window installation, application of siding, and the other conventional building practices — unless energy-efficient practices deviate significantly from the norm. Thus, except where specifically noted, it should be assumed that EE construction generally follows standard techniques.*

The next chapters cover the range of **special** EE techniques topic-by-topic. Because of its particular importance, installation of the air-vapour barrier (applicable in all parts of the house) is outlined first, in Chapter 2. The subsequent chapters discuss EE measures for particular parts of the house, from the ground up. For the sake of clarity and ease of reference, the detailed step-by-step instructions are presented in a series of Worksheets. Any general discussions and explanations appear as normal text.

In reviewing this material, it is important to realize that there are a variety of ways to achieve high levels of energy efficiency. There is no one "right" way, for instance, to insulate a wall — so a number of options are identified and illustrated here. Depending upon the particular house design selected, these options may be modified — as long as the general principles of EE housing are respected and careful workmanship is applied.

* For a comprehensive treatment of standard techniques, refer to *Canadian Wood-Frame House Construction*, metric edition. NHA 5031M. (Ottawa: Canada Mortgage and Housing Corporation, 1981.) See also: *A Glossary of House-Building and Site Development Terms*. NHA 1165. (Ottawa: Canada Mortgage and Housing Corporation, 1982.)

Chapter 2

Air-Vapour Barriers

Installation

The air-vapour barrier of an energy-efficient house **must** be installed in such a way that it provides a nearly completely sealed building envelope. Because of this requirement, the barrier affects all parts of the house: foundations, headers, walls, and ceilings.

The basic sealing procedures, which are common wherever the barrier is installed, are outlined in Worksheet A. Special procedures for dealing with windows, doors, headers, vents, and other obstacles or problems are outlined in subsequent chapters, as they arise.*

Worksheet A

Air-Vapour Barrier Installation

Refer to Figure 7.

1. Polyethylene sheet is normally recommended for air-vapour barriers. The 0.150 mm thickness is recommended, due to its greater resistance to damage during construction (compared to the 0.05 mm and 0.100 mm thicknesses).

2. All joints between two sheets of polyethylene should be made against a solid wood backing. A continuous bead of caulking material — acoustical sealant is recommended — should be run along the joint between the two sheets. The two sheets should then be pressed lightly together along the line of the sealant, and the joint should be strengthened by driving staples through the bead into the wood

* For difficult sealing problems not covered in subsequent chapters, readers may wish to refer to Eyre, D. and D. Jennings, *Air-Vapour Barriers*. (Ottawa: Energy, Mines and Resources. Third edition, March 1982.)

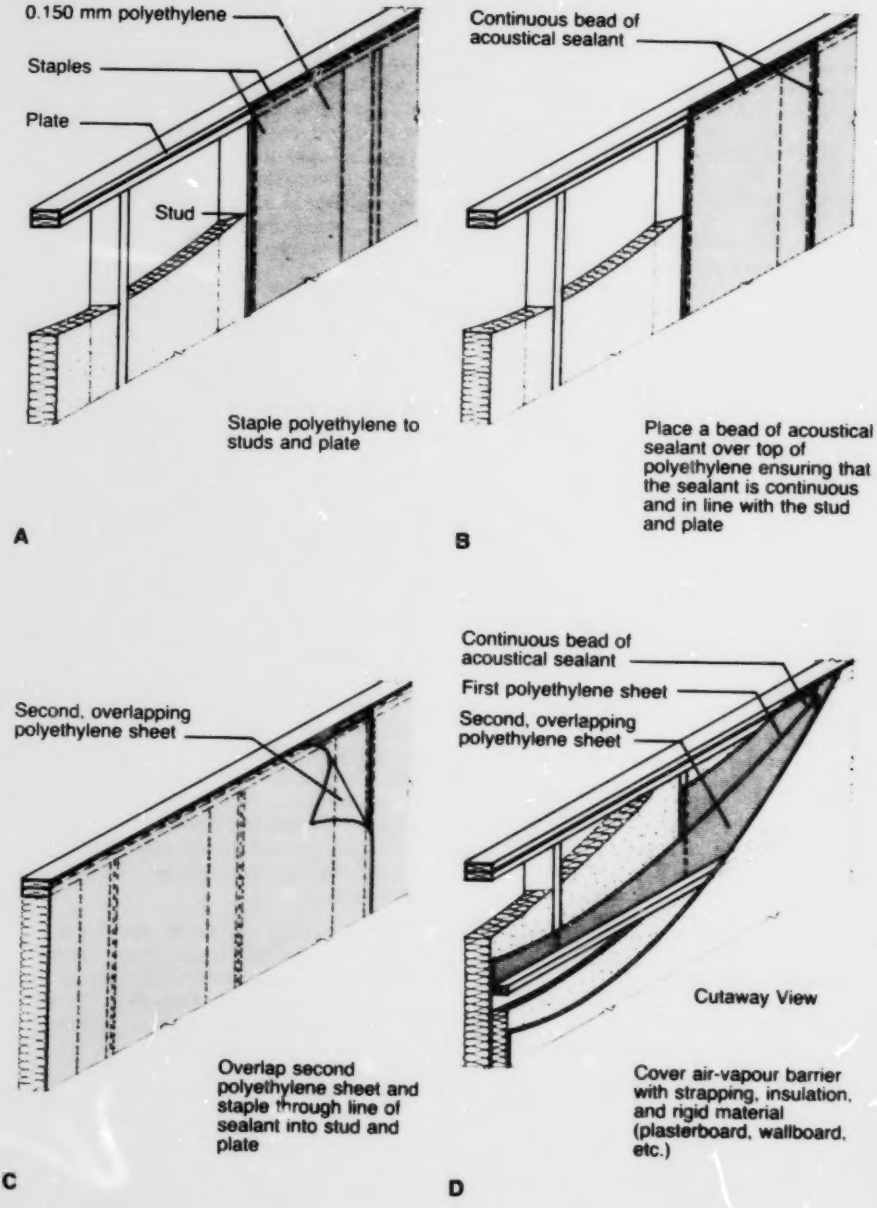

0.150 mm polyethylene
Staples
Plate
Stud
Staple polyethylene to studs and plate
A
Continuous bead of acoustical sealant
Place a bead of acoustical sealant over top of polyethylene ensuring that the sealant is continuous and in line with the stud and plate
B
Second, overlapping polyethylene sheet
Overlap second polyethylene sheet and staple through line of sealant into stud and plate
C
Continuous bead of acoustical sealant
First polyethylene sheet
Second, overlapping polyethylene sheet
Cutaway View
Cover air-vapour barrier with strapping, insulation, and rigid material (plasterboard, wallboard, etc.)
D

Figure 7. Sealing air-vapour barrier

backing. It must be emphasized that the sealant should not be considered to be an adhesive. It cannot be relied upon to hold two sheets of polyethylene together without the support of staples.

3. It must also be emphasized that the use of the correct caulking compound is extremely important. The material must seal the two sheets of polyethylene and maintain the seal over a period of years. The sealant must therefore be pliable and non-hardening (i.e. it must remain pliable). The recommendation of acoustical sealant is based upon these criteria. Note also that the sealant should be installed at the manufacturer's recommended temperatures.

4. At the joint between two large sheets of polyethylene, the two sheets should be overlapped by at least one stud space or one truss space. The lapped barrier should be sealed and stapled at one stud/truss, and simply stapled (sparingly) at the other.

5. Joints should be stapled at intervals of about 150 mm. If the polyethylene sheet is very wrinkled at the joint, an extra amount of sealant and a closer spacing of staples will be necessary. Care should be taken to ensure that the extra material is not sufficient to raise the drywall when it is eventually applied.

6. When installing a sheet of polyethylene at an inside corner, at least 150 mm of spare material should be allowed; this will prevent the barrier from being pulled tight and damaged during subsequent drywall installation.

7. Generally speaking, it is better to use too much sealant and polyethylene sheet, rather than too little.

8. If wind forces are likely to be a problem during construction, all stapled joints and all stapled attachments of the sheet to the wood frame should be strengthened by driving the staples through pieces of strong tape placed on the sheet at the stapling point. One way of relieving the wind loading on the air-vapour barrier is to leave out a large section of the ceiling barrier — about 10 m^2 — which is later sealed and stapled in place just before the drywall is installed.

9. Where the polyethylene sheet is likely to be damaged during construction it should be protected with sheets of plywood or panel material. Typical examples occur on the outside of floor headers, where the sheet can be protected with a permanent covering of plywood. Also, in some preparatory work, a loose strip of polyethylene is left at the base of the walls, ready to be joined later to the wall air-vapour barrier. A temporary protective strip of material should be laid on top of this exposed barrier, particularly at exterior doors.

10. When the air-vapour barrier installation is complete, and before it is covered by other work, it should be given a careful inspection for damage or poor joints. Small holes in the barrier can be repaired with vapour barrier tape; large holes or rips can be repaired with a generously sized patch of polyethylene, caulked to give a thoroughly sealed joint. Where possible, patches should be made large enough to cover the damage and overlap any wood frame nearby, so that the seal can be strengthened with staples.

11. Some minor nail punctures of the barrier are inevitable. These occur when the barrier is sandwiched between two pieces of wood that are nailed together. Air leakage in such circumstances is minimal.

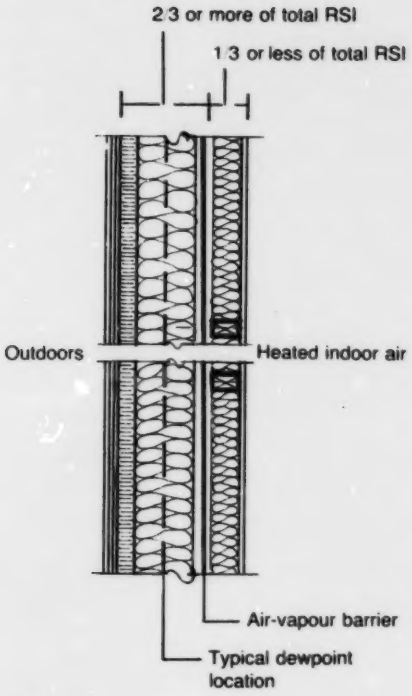


Figure 8. Placing of air-vapour barrier

Position of the Air-Vapour Barrier

Traditionally, air-vapour barriers have been placed on the warm side of any insulation. As was discussed in Part I, this is intended to prevent moisture from entering the wall or attic space where cooling can cause condensation.

This is good practice. However, in energy-efficient housing, it is desirable to place the air-vapour barrier **between** layers of insulation. This protects the barrier from damage during construction. Instead of being penetrated by plumbing and electrical outlets, or damaged during drywall installation, the barrier can remain intact. This is of particular importance in walls, where damage is especially common.

So long as there is at least twice as much insulation on the cold side of the barrier as on the warm side, burying the air-vapour barrier is an acceptable practice. Condensation does not take place until air has cooled to the temperature known as its "dewpoint". Since the temperature within an insulated wall or roof declines gradually from the inside to the outside, the dewpoint temperature is reached somewhere **inside** the wall. If the air-vapour barrier is on the warm side of the dewpoint, no condensation will take place. As illustrated in Figure 8, this is typically achieved, in southern Canada, by following the guideline just noted (that is, twice as much insulation outside the barrier as inside). In areas with over 6500 heating degree days annually (see Figure 3), this rule-of-thumb would not apply: less insulation should be placed inside the barrier.

A Note on Moisture Barriers

Elsewhere in this book, the term moisture barrier will be encountered. These barriers are quite distinct from air-vapour barriers. Instead of preventing moisture that originates inside the house from escaping, they are intended to prevent moisture originating in the soil around the foundation from entering the basement or crawl space. Moisture barriers are most commonly applied under basement or crawl space floors and on the inside surface of concrete foundation walls. (By this definition, the term dampproofing is confined to the coating of the **outside** of a concrete foundation wall. See Figure 9.)

Depending upon the application, either standard dampproofing materials or polyethylene may be used as a moisture barrier. Regardless, no attempt is made to seal the moisture barrier as tightly as the air-vapour barrier. Consequently, the small quantity of moisture that might cross the air-vapour barrier does not remain trapped; instead, it escapes to the outside.

In some circumstances, the moisture barrier can "double" as an air-vapour barrier. A few such cases are noted in Chapter 3.

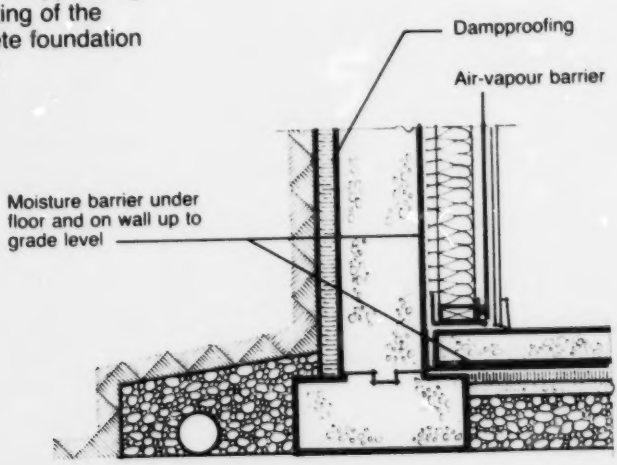


Figure 9. Air-vapour barrier, moisture barrier, and dampproofing

Chapter 3

Foundations

This chapter considers basement walls in concrete and preserved wood, basement floors, crawl spaces, and slabs-on-grade.

Basement Walls — Concrete

There are two principal construction options for basement walls in energy-efficient houses: concrete and preserved wood. The discussion in this section refers to concrete foundations, both poured and block.

It is generally better practice to insulate concrete foundation walls on the outside rather than the inside. There are four reasons for this:

1. The foundation is insulated against climatic temperature variations, and so is less likely to be damaged by cracking.
2. The foundation wall is inside the insulation, and so its mass acts as a medium for heat storage. This helps to reduce the daily temperature swings that arise in the house as a result of passive solar gains.
3. The exterior insulation protects the dampproofing and may form a second barrier against water leakage into the foundation wall.
4. Newly poured concrete walls take several months to cure. This is a drying process — so if the foundation is insulated on the inside, the airtight air-vapour barrier traps moisture emitted from the inside face of the concrete. The build-up of moisture behind the air-vapour barrier can cause water damage to the stud frame and the sill plate.

In spite of these factors, there are circumstances where interior insulation is applied, either instead of, or in addition to, exterior insulation. In colder climates, for instance, it may be difficult to achieve the desired RSI values with exterior insulation alone. More commonly, the builder may, for a variety of reasons, find the installation of interior insulation to be more convenient. Accordingly, though the technical advantages of exterior insulation are clear, installation details for interior insulation are provided in Worksheets D and E and the accompanying text. Worksheets B and C and the accompanying text cover the necessary steps for exterior insulation. Worksheet F covers a few special problems in concrete wall insulation.

Application of Exterior Insulation

Either rigid board insulation (extruded polystyrene) or fibreglass/mineral fibre may be used in the exterior insulation of foundations. These two alternatives are covered in Worksheets B and C respectively.

Worksheet B

Basement Walls/ Exterior Insulation/ Rigid Board

Refer to Figure 10.

1. RSI values equal to or greater than those indicated in Table 1 should be used. The insulation should extend down to the footing.

2. As in conventional construction, it is mandatory to coat the exterior of the foundation with dampproofing and good practice to provide a moisture barrier on the interior (below grade only, in both cases). Standard dampproofing materials may be used as a moisture barrier.

3. The insulation is best attached to the foundation with concrete nails driven into the foundation. The lateral loading of the soil can be used to hold the bottom edge of the insulation against the foundation. Note that the irregularities in the concrete surface make it difficult to adequately secure the insulation to the concrete with adhesive.

4. Above grade, and for at least 300 mm below grade, the exposed face of the insulation must be protected either with pressure treated plywood or with parging. If parging is used, it is best to apply it using the traditional wire mesh technique or using fibreglass reinforced parging.

5. Figure 10 shows a single layer of rigid insulation. If, however, a suitable thickness is unavailable, two thinner sheets should be bonded together with a suitable adhesive, and secured to the foundation as noted in step 3. The outer insulation layer should be carried to the top of the gravel drainage.

6. If the foundation, is made of concrete blocks rather than poured concrete, it is good practice to use solid blocks for a row at grade level, to interrupt convection currents in the hollow cores.

Worksheet C

Basement Walls/ Exterior Insulation/ Fibreglass or Mineral Fibre

1. Rigid fibreglass/mineral fibre insulation is an acceptable option for insulating the exterior foundation. New types of rigid fibre materials, designed specifically for this application, are available commercially. Except as noted in points 2 and 3 of this worksheet, application details (including recommended RSI values) are as outlined for rigid board insulations.

2. This type of insulation has the advantage of acting as a water-drainage channel down the foundation wall. However, care must be taken to provide a good drainage connection between the insulation and the weeping tile. If this is not done, water may flow through the insulation and get blocked at the footing. This will produce high pressure loading on the foundation wall.

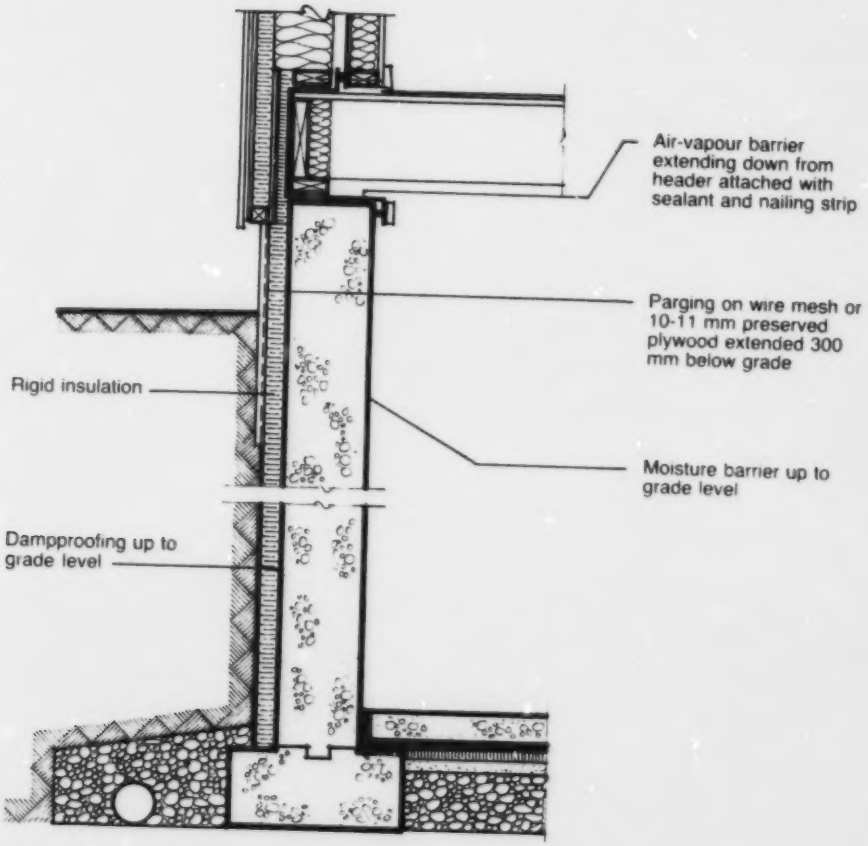

Air-vapour barrier extending down from header attached with sealant and nailing strip
Parging on wire mesh or 10-11 mm preserved plywood extended 300 mm below grade
Rigid insulation
Moisture barrier up to grade level
Dampproofing up to grade level

Figure 10. Exterior insulation on concrete foundation

Application of Interior Insulation

As has been noted, it is preferable to insulate concrete foundations on the outside. If they are, however, insulated on the inside, it is most important to allow the newly poured concrete foundation to cure (dry-out) before sealing it behind an airtight air-vapour barrier. This effectively means that the basement insulation work should not be completed before the end of a minimum curing period of about six months; otherwise structural damage could occur.

If the basement is to be insulated shortly **after** the minimum curing period, leave the header air-vapour barrier hanging loose, and join it directly to the basement wall air-vapour barrier when the basement is being finished. However, if the basement is to be left unfinished for a year or more (that is, if it is sold with an unfinished basement), ensure that the house is airtight by finishing the barrier as shown in Figure 11a. Then, when the basement is to be finished, the continuity of the barrier can be maintained using the technique illustrated in Figure 11b. This final step will depend upon the home's owner.

Two approaches to the actual insulation of the basement are possible: building a stud wall and using fibreglass or mineral fibre batts (Worksheet D), or using a special attachment system with rigid board insulation (Worksheet E).

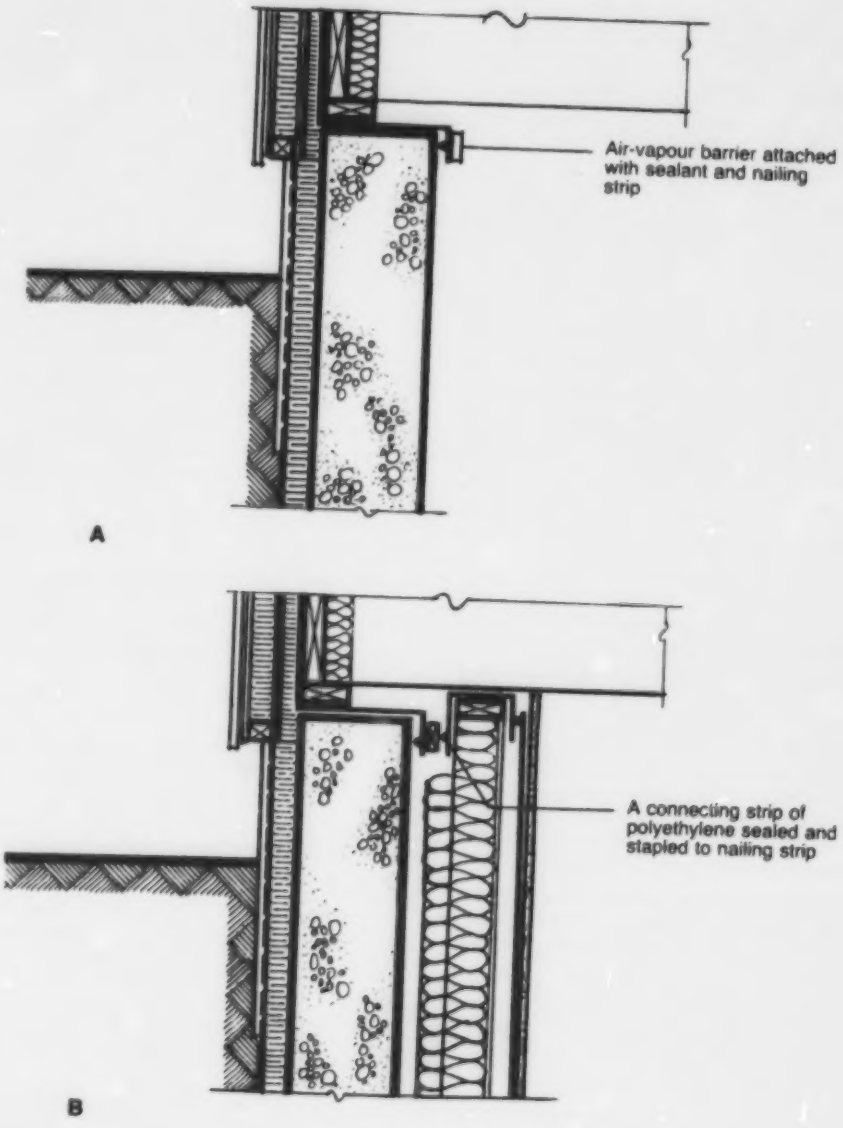

Air-vapour barrier attached with sealant and nailing strip
A
A connecting strip of polyethylene sealed and stapled to nailing strip
B

Figure 11. Allowing foundation to cure before insulating

Worksheet D

Basement Walls/ Interior Insulation/ Fibreglass or Mineral Fibre

Refer to Figure 12.

1. RSI values equal to or greater than those indicated in Table 1 should be used.

2. As in the case of exterior insulation (Worksheet B) it is mandatory to coat the exterior of the foundation with dampproofing, and good practice to provide a moisture barrier on the interior (below grade only, in both cases). Standard dampproofing materials may be used as a moisture barrier.

3. A stud frame is constructed in the usual fashion. It is good practice to install the stud frame about 63 mm clear of the foundation. This allows the installation of an insulation batt (RSI 1.4) laid horizontally behind the studs, to reduce conductive heat loss through the studs ("thermal bridging"). There are no rigid requirements about the thickness of the frame, from an energy-efficiency point of view. It could be a 38 x 63 mm or a 38 x 89 mm stud frame, depending on the level of insulation required.

4. A 0.150 mm polyethylene moisture barrier is placed around the bottom plate to protect it against flow of moisture through the slab.

5. Insulation is installed between the studs, then covered with a continuous 0.150 mm polyethylene air-vapour barrier. Seams in this barrier are lapped and sealed as described in Worksheet A. The barrier is joined, in the same fashion, to the moisture barrier wrapping the bottom plate and the air-vapour barrier extending down from the header. The problem of barrier continuity at partition walls is handled as outlined in Worksheet N. A bead of sealant is placed where the bottom plate meets the floor.

6. Drywall or other interior finish is erected, being careful not to tear the air-vapour barrier. If electrical outlets are to be installed on these walls, procedures for maintaining the integrity of the barrier should be followed. For instance, the wall could be strapped (see Worksheet L). Alternatively, a vapour barrier pan or baseboard wiring could be used (Worksheet N).

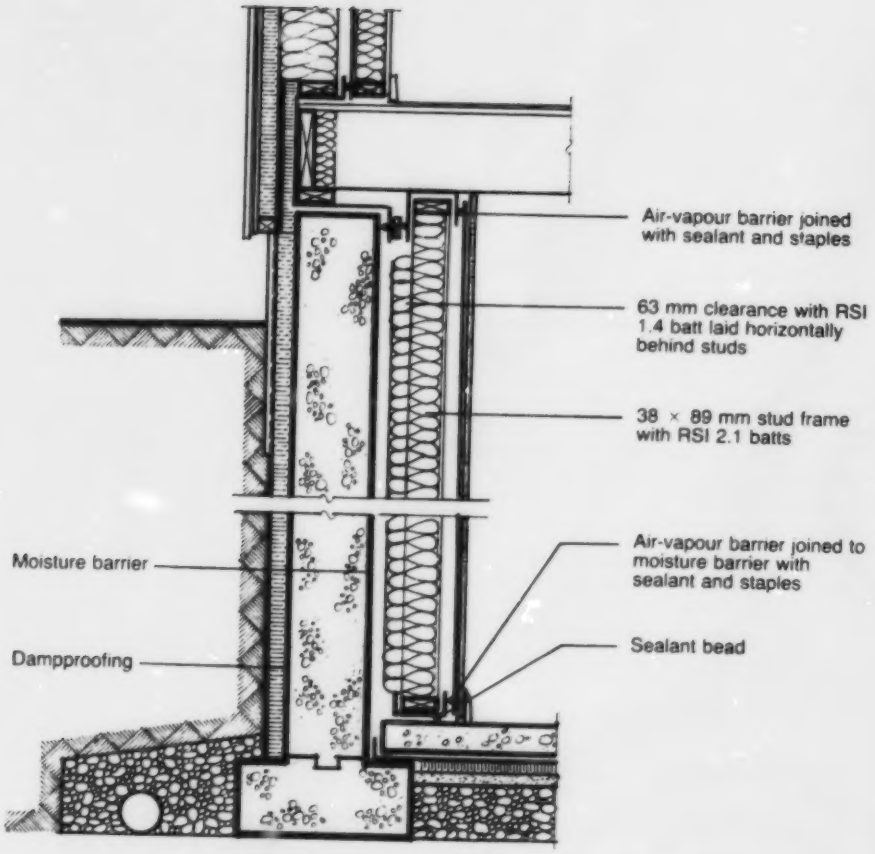

Air-vapour barrier joined with sealant and staples
63 mm clearance with RSI 1.4 batt laid horizontally behind studs
38 × 89 mm stud frame with RSI 2.1 batts
Air-vapour barrier joined to moisture barrier with sealant and staples
Sealant bead
Moisture barrier
Dampproofing

Figure 12. Frame and batt interior insulation

Worksheet E

Basement Walls/ Interior Insulation/ Rigid Board

Refer to Figure 13.

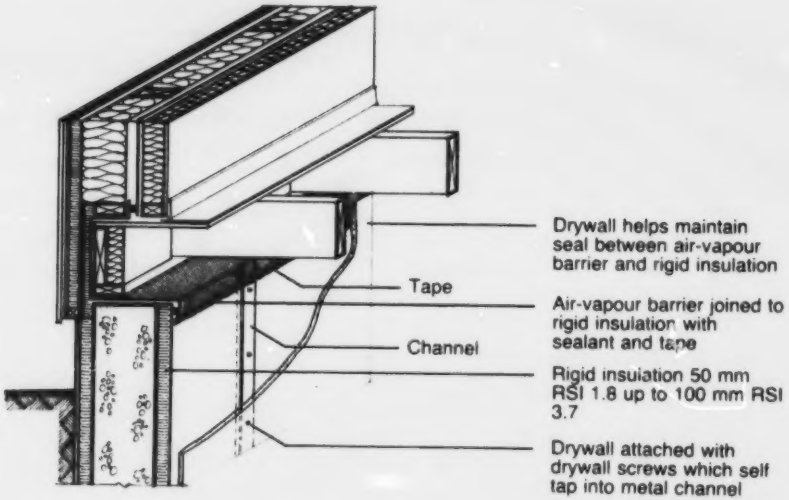
1. RSI values equal to or greater than those indicated in Table 1 should be used.

2. As in the case of exterior insulation (Worksheet B), it is mandatory to coat the exterior of the foundation with dampproofing and good practice to provide a moisture barrier on the interior (below grade only, in both cases). Standard dampproofing materials are recommended for the moisture barrier.

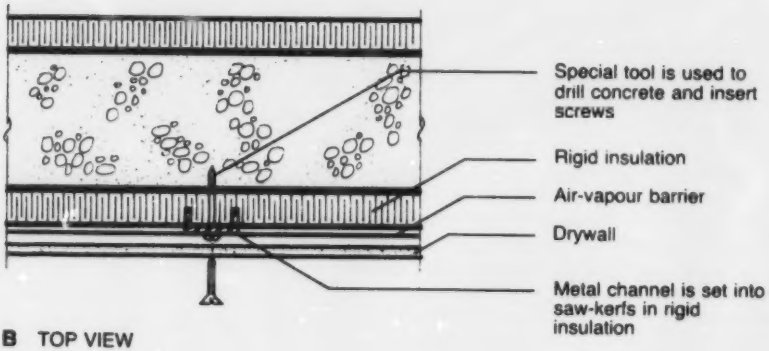
3. The rigid insulation, usually polystyrene beadboard, is attached to the wall with the help of thin metal channels set into saw kerfs in the insulation. A drill with snap-on attachments is used first to drill through the metal and into the concrete. Then a "nail" with a screwed point is drilled into the hole. The drywall is attached over the insulation with self-tapping drywall screws driven into the metal channel. Note that drywall must be used, since most rigid insulations are fire hazards if left unprotected.

4. Since polystyrene has low water vapour permeability, it can be used also as a vapour barrier. The header air-vapour barrier should then be joined to the top of the polystyrene as shown. It is, however, slightly better practice to run the barrier to the foot of the foundation instead of relying on the vapour barrier action of the insulation.

Note: One of the main disadvantages of this system is the conduction bridging through the concrete screws. The concrete will be below freezing during winter, and the conductive heat loss through the screws may cause condensation or frosting on the drywall around the screw heads. Also, this system makes it very difficult to install a hidden electrical system, and it may be necessary to use surface-mounted receptacles — particularly if the receptacle depth is greater than the insulation thickness.


Drywall helps maintain seal between air-vapour barrier and rigid insulation
Tape
Air-vapour barrier joined to rigid insulation with sealant and tape
Channel
Rigid insulation 50 mm RSI 1.8 up to 100 mm RSI 3.7
Drywall attached with drywall screws which self tap into metal channel

A CUTAWAY VIEW


Special tool is used to drill concrete and insert screws
Rigid insulation
Air-vapour barrier
Drywall
Metal channel is set into saw-kerfs in rigid insulation

B TOP VIEW

Figure 13. Attaching rigid insulation to concrete foundations

Special Problems of Concrete Basement Walls

Basement insulation raises a few special problems. Because each of these problems affects more than a single insulation technique, they are considered separately in Worksheet F.

Worksheet F

Basement Walls/ Special Problems

1. If the basement is insulated — whether on the inside or outside — the surrounding soil is deprived of the heating effect of the house and is subjected to much larger temperature swings throughout the year. If the surrounding soil is of the type that displays frost heave or other icing problems, the foundation may have to be given special protection to resist soil loadings.

2. One of the most common house designs in Canada consists of a wood frame on a full concrete basement. In this design, the first floor is commonly supported by a beam set into the concrete. If the basement is developed, the air-vapour barrier has to be fitted around the support beam and sealed. However, the support beam still penetrates the barrier, so that in the case of a made-up wood beam, air can infiltrate at this point — along the gaps between the support beam plies. One solution is to caulk the ply gaps over a distance of at least 600 mm at each end of the support beam, prior to setting the beam into the concrete. Alternatively, a polyethylene bag (such as a garbage bag) can be placed over the end of the beam. The beam is then set into the concrete and the bag later sealed to the air-vapour barrier.

If the beam is steel rather than wood, the problem of plies does not arise. The barrier should still be fitted around the beam and sealed.

3. When a basement is insulated on the interior, it is not good practice to place water pipes in the wall, but where this is necessary the pipes should be placed as close to the inside face of the insulation as possible, to prevent freezing. The pipes should be protected against accidental damage over the full embedded length, using galvanised metal plate screwed or nailed to the studs. This should be installed on the warm side of the air-vapour barrier so that the barrier is also protected.

4. Pipes or vents passing through the foundation should be caulked (if the insulation is on the outside) or sealed as shown in Figure 39 (if the insulation is on the inside).

5. Basement window frames should, if possible, be sealed to the basement air-vapour barrier using an adaptation of the techniques recommended for other windows (Worksheet Q).

Basement Walls — Preserved Wood

Preserved wood foundations are much less common than concrete foundations, but their use is increasing. Wood that is pressure treated with chemical preservatives is used to build a frame wall; this wall can be insulated by conventional methods.

Worksheet G

Basement Walls/ Preserved Wood

Refer to Figure 14.

1. Pressure-treated wood foundations should conform strictly to the national standard published by the Canadian Standards Association.* No contravention of these specifications is necessary in energy-efficient construction.

2. RSI values equal to or greater than those indicated in Table 1 should be used. Fibreglass batts are recommended.

3. Supplementary measures necessary for EE housing include the sealing of the seams of the wall air-vapour barrier, using the standard techniques described in Worksheet A. The barrier should also be joined, in the same fashion, to the barrier extending down from the header. The detailing required to ensure an effective seal at obstructions is similar to that used for above-grade walls (Worksheet N).

4. The air-vapour barrier is sealed, with a bead of sealant and staples, to the screed board at the bottom of the wall. This substitutes for a direct connection to the floor moisture barrier, necessary because the wall air-vapour barrier cannot be installed until the concrete floor is in place — otherwise it would be damaged during pouring. The screed board is the only continuous piece of wood to which the air-vapour barrier can be sealed and stapled.

5. The exterior insulating sheathing is extended down from the wall above to below the header, to reduce the high conduction losses through the top plates of the wall.

Note: The preservative treatment of wood is the impregnation of wood with chemicals to prevent fungal decay and termite attack.

Usually the preservative solution is forced into the wood by applying pressures up to 150 psi. Preservatives may be classified into three groups: 1) creosote and creosote solutions, 2) oil-based chemicals such as pentachlorophenol, and 3) waterborne inorganic compounds such as chromated copper arsenate (CCA) and Ammoniacal copper arsenate (ACA).

All wood preservatives are considered pesticides and must be registered under the Pest Control Products Act administered by Agriculture Canada.

At present lumber and plywood used for the construction of preserved wood foundations must conform to the requirements of CSA standard 080.15, "Preservative Treatment of Wood for Building Foundation System, Basements and Crawl Spaces by Pressure Processes." Only two preservatives are permitted: chromated copper arsenate (CCA) and ammoniacal copper arsenate (ACA), both of which are waterborne inorganic arsenical preservatives. Wood treated with creosote or pentachlorophenol must not be used in the construction of preserved wood foundations.

As with any chemical, precautions should be taken to minimize exposure. Wood pressure-treated with waterborne inorganic arsenical preservatives including wood foundation products may be used exposed inside residences provided any dust is removed from the wood surface. When handling wood, normal worker hygiene should be practised. Use gloves to avoid splinters, wear a dust mask to avoid prolonged inhalation of sawdust when sawing, and wash exposed areas after skin contact with treated wood. Treated wood should be disposed of by ordinary trash collection or burial, never burnt in open fires, stoves or fireplaces.

Studies undertaken by the U.S. Environmental Protection Agency conclude the preservative in treated wood foundation material is neither released into the air nor absorbed through skin contact. CCA and ACA are safe, effective preservatives used to prolong the service life of wood products.

* Preserved wood foundations must conform to the requirements of CAN3-S406-M83, "Construction of Preserved Wood Foundations". Adherence to this standard will complement energy-efficient construction.

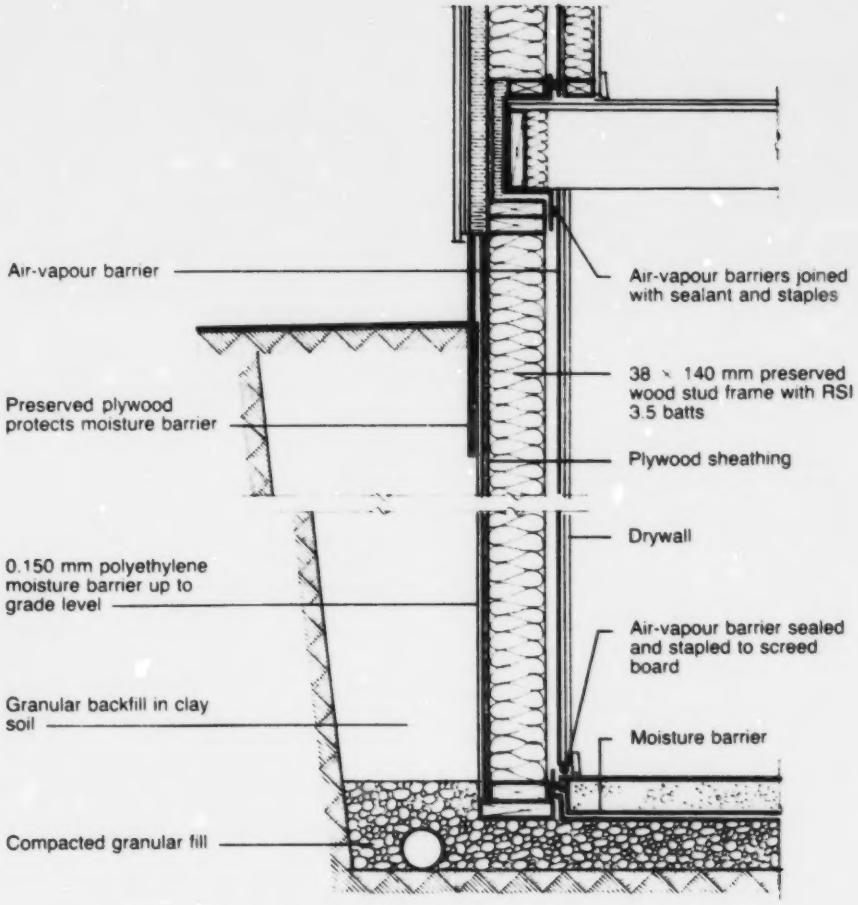

Air-vapour barrier
Preserved plywood protects moisture barrier
0.150 mm polyethylene moisture barrier up to grade level
Granular backfill in clay soil
Compacted granular fill
Air-vapour barriers joined with sealant and staples
38 × 140 mm preserved wood stud frame with RSI 3.5 batts
Plywood sheathing
Drywall
Air-vapour barrier sealed and stapled to screed board
Moisture barrier

Figure 14. Insulation of preserved wood foundation

Basement Floors

It is desirable to install **moisture** barriers beneath basement floors and, in most cases, to insulate these floors. The barrier acts primarily to prevent moisture movement from the ground into the house, but it also reduces the infiltration of radon gas through the floor (since radon gas is generated mainly in the soil around the house). The insulation reduces heat loss through the basement floor — resulting in warmer floors and a small (but not trivial) energy saving. Worksheet H outlines the approach for houses with concrete foundations.

Worksheet H

Basement Floors/ Insulation Below Slab

Refer to Figure 15.

1. RSI values equal to or greater than those indicated in Table 1 should be used. Rigid polystyrene insulation is recommended.

2. The insulation is laid down on the compacted fill and covered with a 0.150 mm polyethylene moisture barrier. A layer of sand may next be placed on top of the polyethylene to facilitate curing of the concrete slab, which is poured on top of the sand.

3. From a practical point of view it is very difficult to do all this properly. When the slab is being poured, the concrete is moved around with wheelbarrows and shovels; there is a considerable risk of damaging either the insulation or the moisture barrier. If extra care is taken during slab pouring, it might be possible to retain the integrity of the moisture barrier and insulation.

4. If intact, the moisture barrier can also act as an air-vapour barrier, and can, in theory, be joined to the main house air-vapour barrier (if the basement wall is insulated inside) to give a completely sealed envelope. In practice, the moisture barrier will be shredded where it projects above the edge of the slab, and there will be little chance of achieving an airtight joint. Consequently, it makes most sense to terminate the moisture barrier at the footing, as shown in Figure 15.

5. Note that, even with insulation beneath the slab, a considerable amount of heat can still be lost through the edge of the slab and the footing. This part of the slab normally has the highest heat loss, and the slab insulation does nothing to prevent this. This is not a serious problem, since the resulting warming of the footing and the soil around it is probably beneficial.

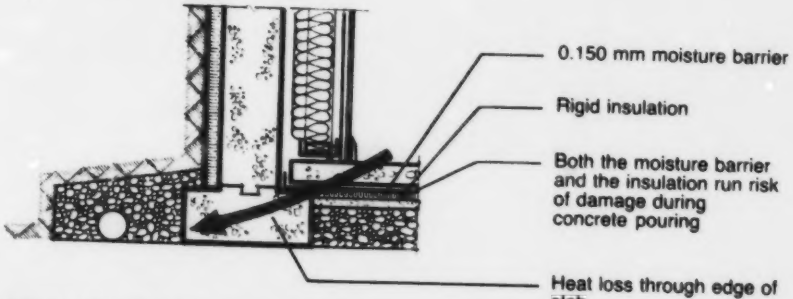

0.150 mm moisture barrier
Rigid insulation
Both the moisture barrier and the insulation run risk of damage during concrete pouring
Heat loss through edge of slab

Figure 15. Insulating basement floors

Basement Floors: Preserved Wood Foundations

The basement floors in houses with preserved wood foundations should be installed in accordance with the guidelines of the Canadian Wood Council.* In energy-efficient houses, a supplementary measure, in the case of a concrete slab floor, is the extension of the moisture barrier up to the bottom plate of the wall. As illustrated in Figure 16, the barrier should be sealed at the plate using the techniques explained in Worksheet A. The moisture barrier is held in position by a nailed screed board installed before the slab concrete is poured. Note that the screed board should extend above the bottom plate of the wall to resist lateral soil loading on the studs. As noted in Worksheet G, the wall air-vapour barrier will later be sealed to the screed board. The net effect will be to block infiltration around the base of the foundation, between the wall and the slab.

Crawl Spaces and Slabs-on-Grade

In building a crawl space, the main requirements are to provide insulation in the right places and to protect the crawl space and house from the effects of moisture build-up. Worksheet I outlines the necessary steps. Worksheet J outlines the energy-efficient approach for slabs-on-grade.

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* See *Construction Guide for Preserved Wood Foundations*, cited in Worksheet G.

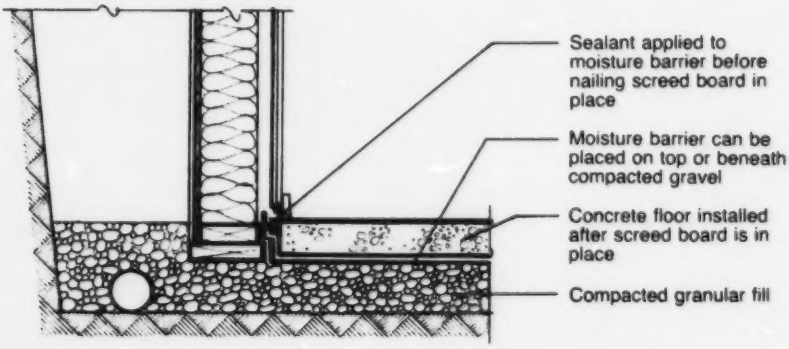
Sealant applied to moisture barrier before nailing screed board in place
Moisture barrier can be placed on top or beneath compacted gravel
Concrete floor installed after screed board is in place
Compacted granular fill

Figure 16. Moisture barrier details with preserved wood foundation and concrete slab.

Worksheet I

Crawl Spaces

Refer to Figures 17 and 18.

1. Since the crawl space is unheated, the main insulation should be provided between the floor joists. RSI values should equal or exceed those indicated in Table 1. If batt insulation is used, it should be supported underneath with wire mesh of a small enough size to prevent rodents from nesting. If loose fill insulation is used, the task of supporting the insulation can be simplified by attaching wood flanges to the bottom of the joists before installation (Figure 17). Thin chipboard can then be dropped in place on top of the flanges. This eliminates the need to work under the joists. The space between the joists should be completely filled with insulation, to make best use of the available space and eliminate any airflow paths. The air-vapour barrier should be positioned on top of the subfloor and sealed as shown in Figure 18, using typical energy-efficient techniques (Worksheet A).

2. Where cables, pipes, vent stacks or heating runs penetrate the floor, any air gaps around them should be sealed positively.

3. The foundation should also be insulated, for two reasons: to help increase the effective insulation level of the house floor, and to help maintain the crawl space temperature above freezing, thereby reducing risks of frost heave or freeze-up damage. This foundation insulation should be placed on the exterior (see Worksheets B and C) to protect the concrete against temperature effects.

4. The polyethylene moisture barrier is installed to restrict the entry of moisture into the crawl space from the earth floor. It should be routed continuously across the grade and up to the outside of the floor header. It should be terminated, with staples (sealant is not essential) above any structural joints in the exterior finish of the house. It should be covered with sand as protection.

5. The crawl space should be vented, with sizes in accordance with current code requirements. The vents should be provided with dampers that can be closed in winter and opened in summer.

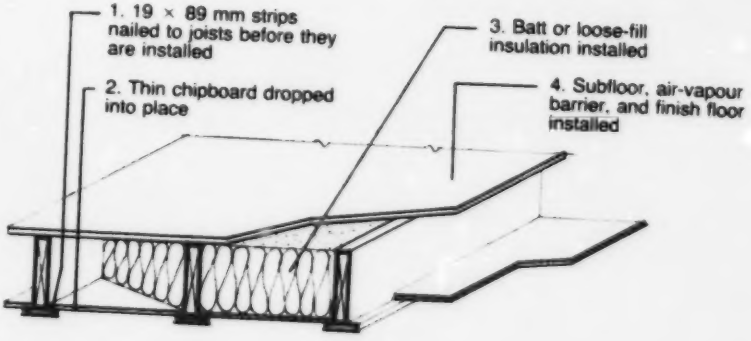
1. 19 × 89 mm strips nailed to joists before they are installed
2. Thin chipboard dropped into place
3. Batt or loose-fill insulation installed
4. Subfloor, air-vapour barrier, and finish floor installed

Figure 17. Technique for insulating floor over crawlspace

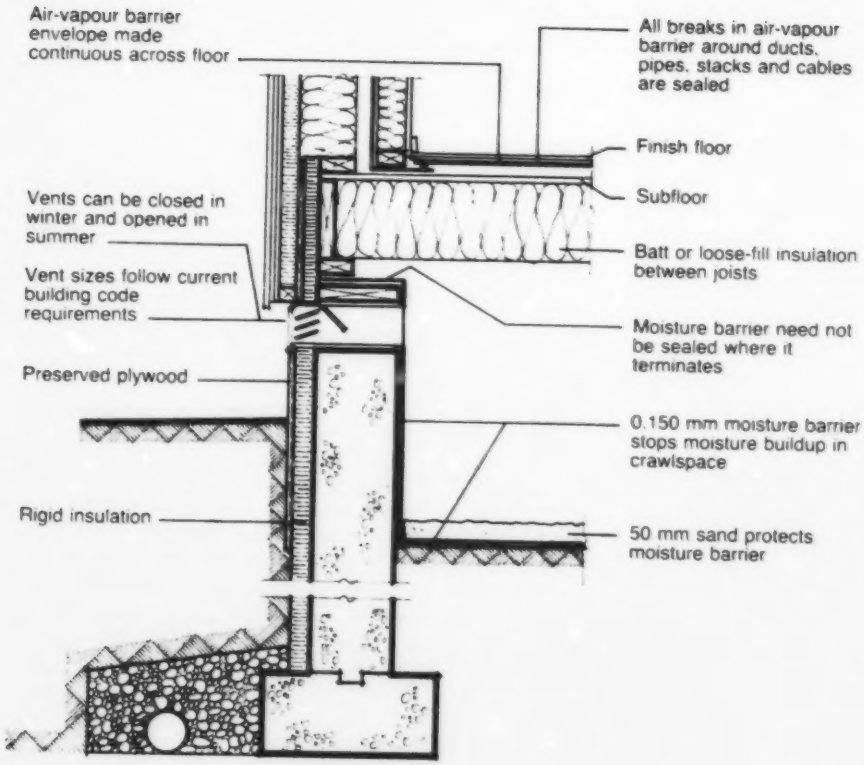
Air-vapour barrier envelope made continuous across floor
All breaks in air-vapour barrier around ducts, pipes, stacks and cables are sealed
Finish floor
Subfloor
Vents can be closed in winter and opened in summer
Batt or loose-fill insulation between joists
Vent sizes follow current building code requirements
Moisture barrier need not be sealed where it terminates
Preserved plywood
0.150 mm moisture barrier stops moisture buildup in crawlspace
Rigid insulation
50 mm sand protects moisture barrier

Figure 18. Details of crawlspace insulation

Worksheet J

Slabs-on-Grade

Refer to Figure 19.

1. Slabs-on-grade should be insulated on the outside of the foundation, following the general procedures outlined for basement walls in Worksheets B and C.

2. Extruded polystyrene or rigid fibreglass mineral fibre insulation should be applied with the RSI values equalling or exceeding the figure given in Table 1.

3. The details of air-vapour barrier routing and sealing (using techniques from Worksheet A) are illustrated in Figure 19.

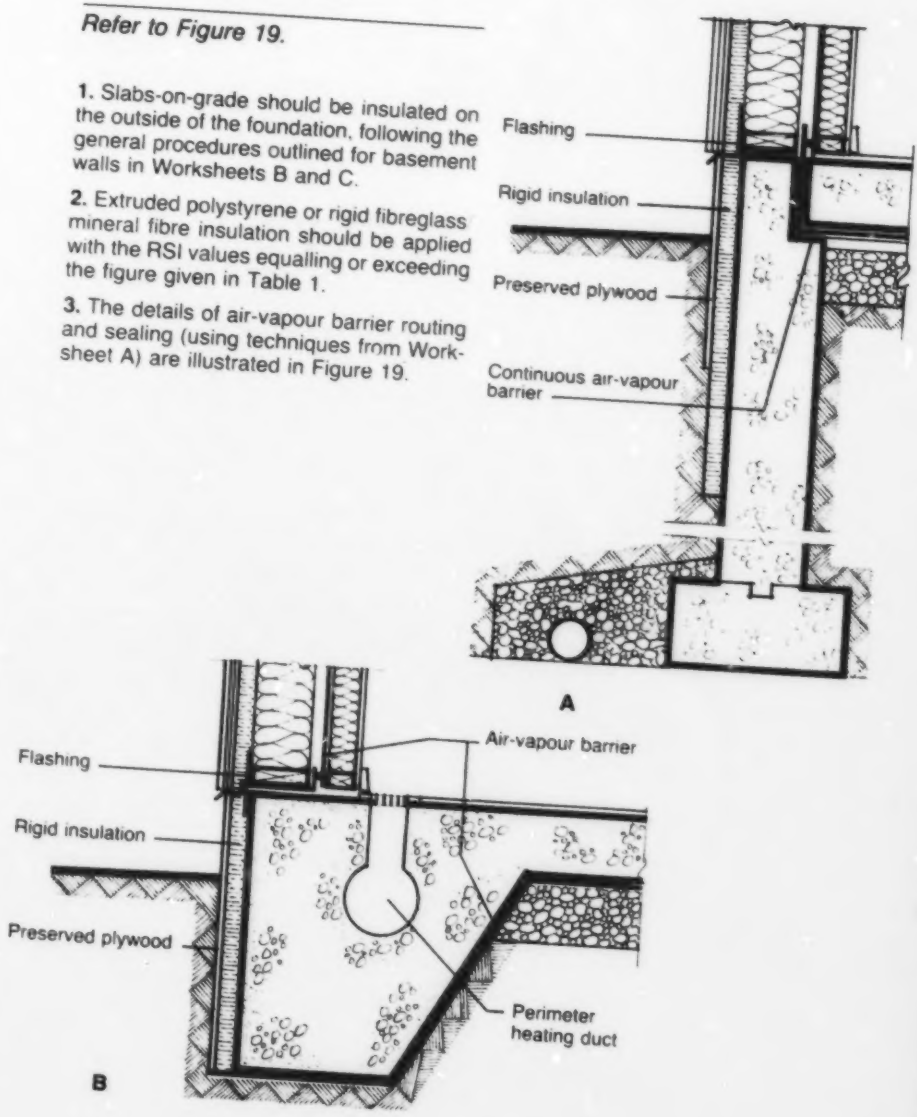

Figure 19. Details of slab-on-grade insulation

Chapter 4

Headers

The headers are major points of air leakage if they interrupt the air-vapour barrier, and of heat loss if they are not insulated. Worksheet K outlines the steps to be taken at the first-floor headers in order to achieve energy-efficient construction.

The steps to be taken at the headers between the first and second floor are not considered separately. The approach is, however, essentially the same as in the basement-to-first floor case, requiring only minimal adaptation of the steps described below.

Worksheet K

First-Floor Headers

1. A preparatory strip of polyethylene must be installed around the header during framing (see Figure 20), ready to join to the wall air-vapour barriers, above and below, at a later stage.

2. The polyethylene is easily damaged by the joists when they are being installed, and can also be damaged by the rough foundation wall. This damage can be avoided by running the strip between the sill plate and a felt or foam pad, as shown in Figure 20.

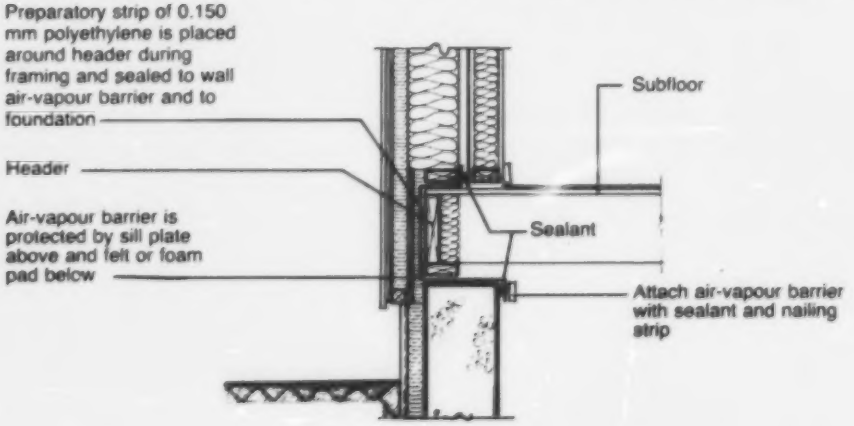
Preparatory strip of 0.150 mm polyethylene is placed around header during framing and sealed to wall air-vapour barrier and to foundation
Header
Air-vapour barrier is protected by sill plate above and felt or foam pad below
Subfloor
Sealant
Attach air-vapour barrier with sealant and nailing strip

Figure 20. Air-vapour barrier at first-floor header

3. As was discussed in the previous chapter, it is not recommended that the foundation of an EE house be insulated entirely on the inside. However, if this is the case, the sill plate will experience low temperatures due to heat loss through the concrete. In such circumstances, the sill plate must be placed outside the air-vapour barrier, to avoid condensation damage. A strip of plywood should be nailed to the sill plate before the joists are installed, to protect the polyethylene.

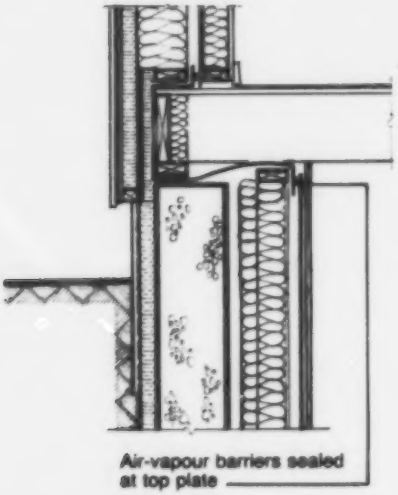

Figure 21. Routing of air-vapour barrier if foundation insulated inside and outside

4. The header air-vapour barrier is joined to the air-vapour barrier from the wall above using the typical techniques (see Worksheet A). If the basement is to be insulated on the outside, the header air-vapour barrier must be terminated as shown in Figure 20, to maintain airtightness at the free edge. The wood nailing strip provides a good take-off point for the basement air-vapour barrier, if the basement interior is to be developed at a later stage (see Figure 11). Alternatively, if interior basement insulation is to be installed at an early date (after allowing suitable curing time for the concrete foundation), the polyethylene can initially be left loose, for later finishing as shown in Figure 21.

5. There is a natural tendency to place a great deal of insulation in the convenient space between joists. This is wrong (in an energy-efficient house) because the air-vapour barrier is outside the header. As discussed in Part II, Chapter 2, there must be at least twice as much insulation outside the barrier as inside. Batt-type insulation can be installed, therefore, but the quantity must be limited, as shown in Figure 22.

6. Additional exterior insulation can be supplied in a number of ways, depending upon construction detail. For instance, insulating sheathing can be extended downwards from the first floor and exterior insulation can be extended up from the basement, as illustrated in Figure 22. Note that the bottom plate of the first floor wall is set back so that extra insulation can be positioned to reduce heat loss through the plate. An alternative approach is illustrated in Figure 23, in which an additional layer of insulation has been incorporated. Note, in both Figures 22 and 23, the provision of 10-11 mm plywood between the insulation layers, to act as a nailing support for the siding.

Note: Some double frame wall designs require unusual placement of the header. These are discussed in the next chapter.

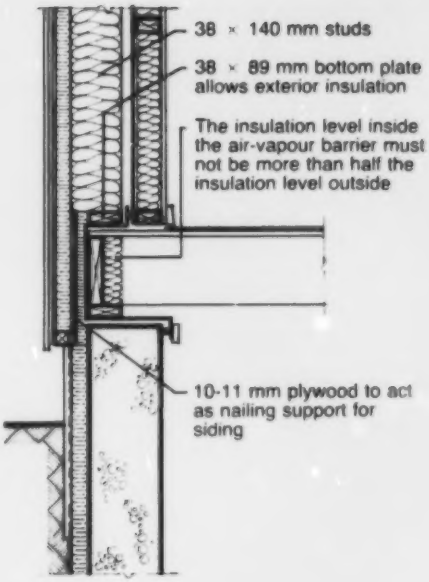
38 × 140 mm studs
38 × 89 mm bottom plate allows exterior insulation
The insulation level inside the air-vapour barrier must not be more than half the insulation level outside
10-11 mm plywood to act as nailing support for siding

Figure 22. Header insulation

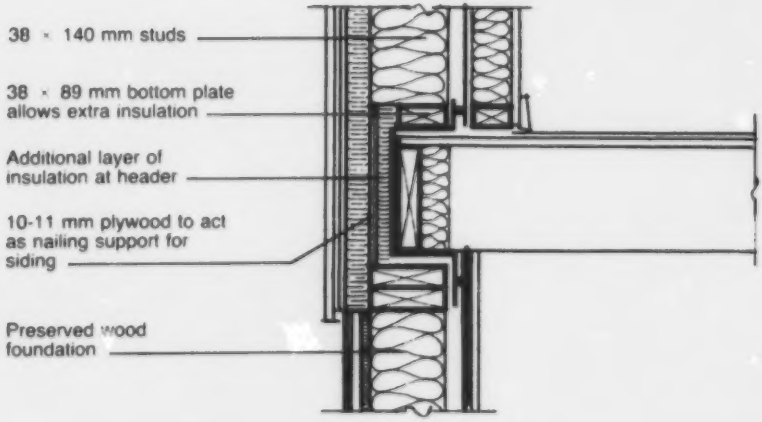
38 × 140 mm studs
38 × 89 mm bottom plate allows extra insulation
Additional layer of insulation at header
10-11 mm plywood to act as nailing support for siding
Preserved wood foundation

Figure 23. Header insulation

Cantilevered Floors and Attached Garages

Cantilevered floors are projections of the floor joists and header beyond the wall below, to create an overhang and additional floor space for upper rooms (see Figure 24). This design creates problems in bridging the gap between the first floor and basement air-vapour barriers. It is very easy to run the barrier on the cold side of the floor insulation — but in cases where this has been done, there has been rapid deterioration of the floor at this point. A better solution, illustrated in Figure 24, is to use polystyrene insulation as a bridging section of air-vapour barrier — an intricate and time-consuming measure. Avoiding the use of cantilevered floors in an EE house design is a preventative approach to these problems.

In some designs an attached (unheated) garage creates very similar problems. In such cases, the basic approach illustrated in Figure 24 should be adapted to provide the required air-vapour barrier continuity.

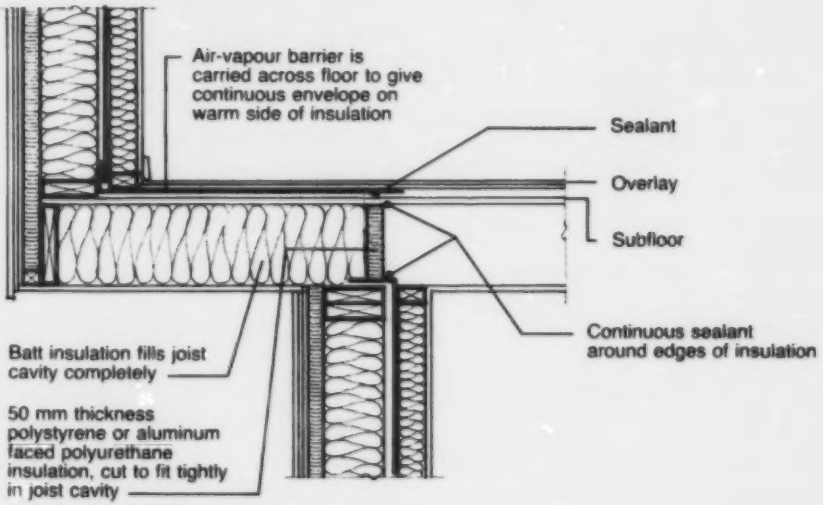
Air-vapour barrier is carried across floor to give continuous envelope on warm side of insulation
Sealant
Overlay
Subfloor
Continuous sealant around edges of insulation
Batt insulation fills joist cavity completely
50 mm thickness polystyrene or aluminum faced polyurethane insulation, cut to fit tightly in joist cavity

Figure 24. Cantilevered floor

Chapter 5

Walls

Traditional wall construction techniques seriously restrict the level of energy-efficiency that can be achieved. To overcome this restriction, a number of new, multi-layer wall designs have been developed and are now in use.

In addition to allowing much higher insulation levels, one of the main incentives for developing these designs has been the fact that they allow greater flexibility in the positioning of the air-vapour barrier. The standard 38 x 89 mm stud frame wall makes it mandatory to install the vapour barrier on the inner face of the frame. In contrast, the multi-layer designs allow the barrier to be buried inside the wall structure, between two of the layers. The theory and advantages of this have been discussed in Part II, Chapter 2.

Another benefit of multi-layer walls is that they provide an opportunity to block thermal bridging. Thermal bridging is the excessive loss of heat through those structural elements of the building with low insulation properties (such as studs and ceiling joists). Multi-layer designs allow the thermal bridge to be interrupted by a layer of insulation.

The best known of these multi-layer walls are the strapped single stud wall and the double stud wall. The choice between single and double stud construction involves several considerations. Double walls can be built to almost any thickness, to achieve very high insulation levels. However, the strapped single stud wall produces insulation levels nearly as high as the RSI values recommended in Table 1 — so the extra thickness of double walls may not be an advantage. Double walls use exclusively or primarily 38 x 89 mm studs, whereas single stud walls use 38 x 140 mm studs, which may be expensive or difficult to obtain in some areas. On the other hand, double walls are a less proven technique and they do raise some problems with respect to outer wall movement (discussed in Worksheet M).

The choice between the two techniques should be made carefully. Generally, the single stud technique appears to be a favoured approach, since it requires a less significant departure from standard practice.

Common variations of these two wall types are covered in Worksheets L and M respectively. Worksheet N discusses techniques for use in the sometimes difficult task of sealing the wall air-vapour barrier at obstructions.

Worksheet L

Single Stud Walls

Refer to Figure 25.

1. Energy-efficient single stud walls have 38 x 140 mm studs. The studs are strapped inside with 38 x 64 mm horizontal strapping, placed on edge.

2. Batts are installed in the stud frame and between the strapping, and the exterior is

sheathed with rigid insulation (normally polystyrene or fibreglass). Note that the rigid insulation thickness should not exceed 38 mm, to ensure good siding attachment. If the house exterior is sheathed with rigid insulation thicker than 38 mm, the siding nails derive little support in this thickness of insulation, and some movement of the siding nails and the siding may occur. Where it is necessary to use a greater thickness, a nailing support such as 19 x 89 mm or 19 x 64 mm strapping must be provided.

3. With rigid insulation sheathing, cross-braces are needed to give the wall raking strength. Stud spacing should not exceed 400 mm.

4. The air-vapour barrier is installed over the face of the stud frame before the interior 38 x 64 mm strapping is put in place. This removes the air-vapour barrier from the risk of damage by electrical and drywall work. Note that, if the barrier is not to be penetrated by the screws on the back of the electrical receptacles, the width of the strapped wallspace should be at least 64 mm. All joints in the barrier are sealed as outlined in Worksheet A, and the barrier is sealed at corners and to the header and ceiling barriers using the same techniques. The many obstacles to a continuous barrier (such as pipes, windows, doors, and partition walls) require special sealing techniques, which are outlined in Worksheet N.

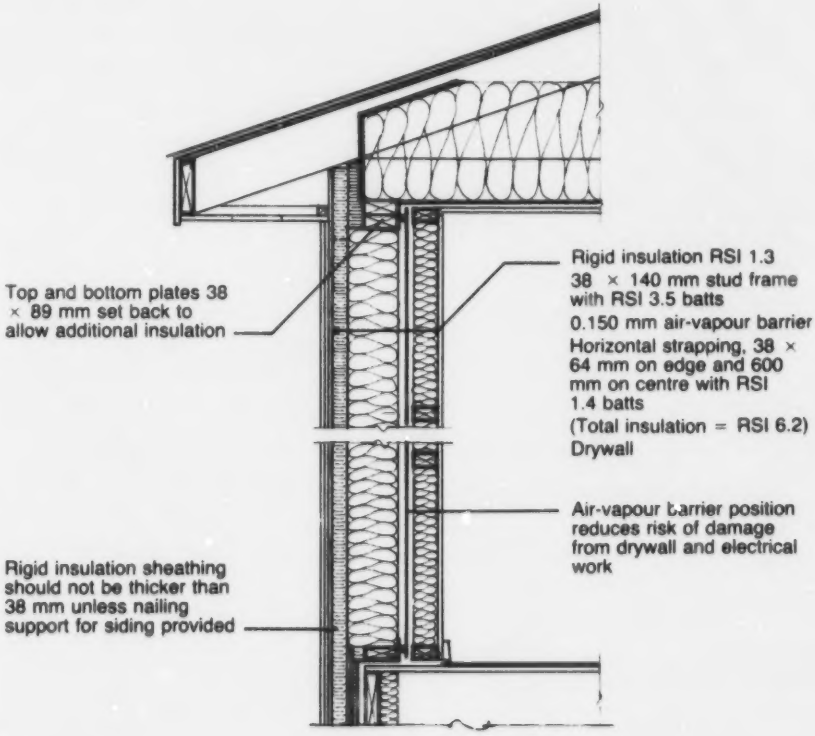
Top and bottom plates 38 × 89 mm set back to allow additional insulation
Rigid insulation RSI 1.3
38 × 140 mm stud frame with RSI 3.5 batts
0.150 mm air-vapour barrier
Horizontal strapping, 38 × 64 mm on edge and 600 mm on centre with RSI 1.4 batts
(Total insulation = RSI 6.2)
Drywall
Air-vapour barrier position reduces risk of damage from drywall and electrical work
Rigid insulation sheathing should not be thicker than 38 mm unless nailing support for siding provided

Figure 25. Single stud wall

5. Although the wall is made of 38 x 140 mm studs, the top and bottom plates are 38 x 89 mm, set flush with the inner face of the studs, as shown. This allows the installation of extra insulation outside the plates, thereby reducing the high conduction heat loss at these points.

6. If the house has a good airtight air-vapour barrier, there is little risk of water vapour movement into the wall structure. However, if the barrier is even slightly defective, there could be some build-up of moisture in the wall unless the house is operating most of the time under negative pressure, which prevents exfiltration of moist warm air.

7. Figure 26 shows two examples of exterior wall construction with brick veneer. With more materials added to the wall section, finding space on the foundation wall for the veneer while retaining adequate support for the joists, becomes the main task. It is accomplished by shifting the sill plate slightly over the interior edge of the foundation.

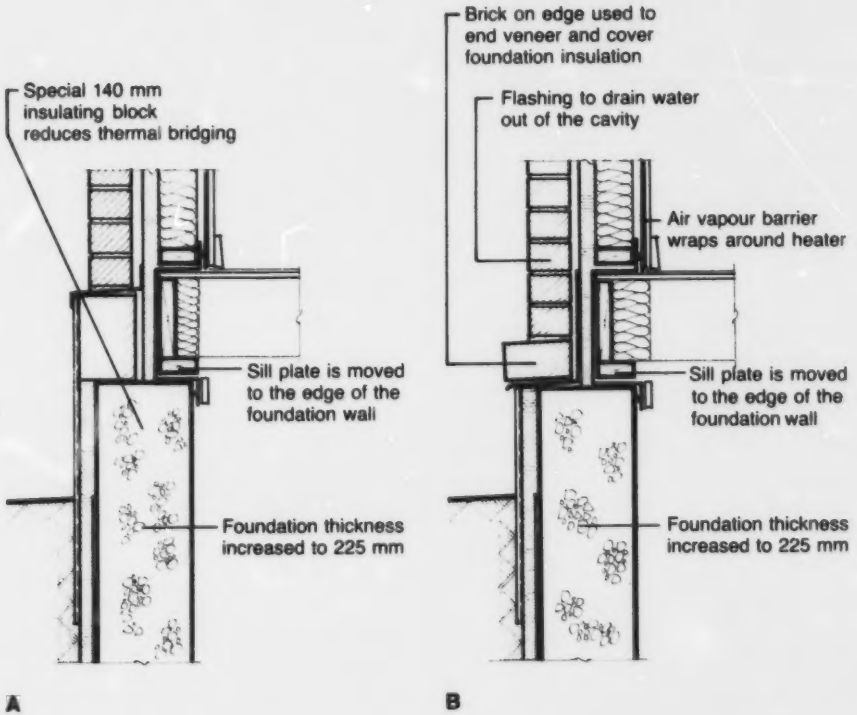
Special 140 mm insulating block reduces thermal bridging
Sill plate is moved to the edge of the foundation wall
Foundation thickness increased to 225 mm
A
Brick on edge used to end veneer and cover foundation insulation
Flashing to drain water out of the cavity
Air vapour barrier wraps around heater
Sill plate is moved to the edge of the foundation wall
Foundation thickness increased to 225 mm
B

Figure 26. Two alternatives for brick veneer support

Worksheet M

Double Stud Walls

Refer to Figure 27.

1. Double stud walls consist of two standard stud walls tied together by plywood top and bottom plates. The total width of the wall is determined by the width of these plates. The inner of the two stud walls is the structural wall.

2. The wall is constructed in the conventional fashion, in the sense that it is constructed horizontally on the floor and then tipped up and into place. The inner wall is constructed first, including both top plates. The polyethylene air-vapour barrier is then placed on top, using EE joining and sealing techniques (see Worksheet A). The sheathing is then nailed on in the conventional manner, thereby protecting the barrier from mishandling and wind effects. Care should be taken not to damage the barrier when cutting the sheathing.

3. The outer stud wall is built next, directly on top of the inner wall. Using temporary spacer blocks, nail the two walls together using the top and bottom plywood plates. Apart from tying the wall together, these plates protect the air-vapour barrier.

4. Blocking is next installed on the sill plate, as illustrated. Note that this requires an unusual positioning of the first floor header, near the inside edge of the sill plate. This blocking serves as a support for the outer wall and as a nailing surface for the finishing material.

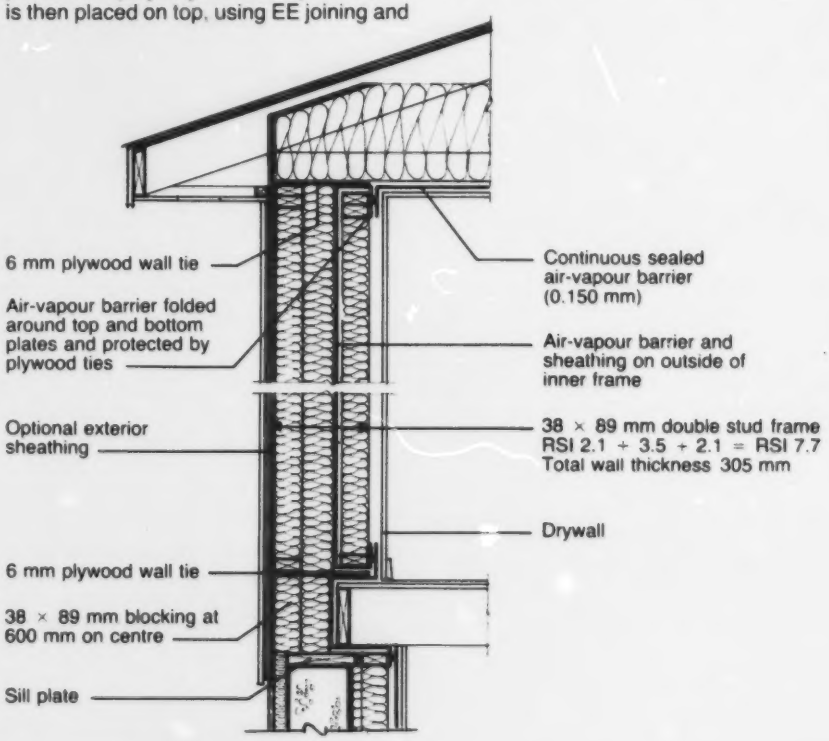
6 mm plywood wall tie
Air-vapour barrier folded around top and bottom plates and protected by plywood ties
Optional exterior sheathing
6 mm plywood wall tie
38 × 89 mm blocking at 600 mm on centre
Sill plate
Continuous sealed air-vapour barrier (0.150 mm)
Air-vapour barrier and sheathing on outside of inner frame
38 × 89 mm double stud frame
RSI 2.1 + 3.5 + 2.1 = RSI 7.7
Total wall thickness 305 mm
Drywall

Figure 27. Double stud wall

5. The wall section is tilted up and put in place (and, in addition, is nailed to the blocking). The air-vapour barrier flaps are stapled to the inner face of the top and bottom plates to prevent damage; later, these flaps will be sealed to the header and ceiling air-vapour barriers using standard EE techniques (see Worksheet A). The outer two cavities of the wall can now be insulated with fibreglass batts when desired. Wiring can be installed inside the air-vapour barrier, without causing damage, before the third layer of insulation is installed.

6. Some houses with this wall design have experienced movement of the outer frame. This is probably due to the fact that the inner frame is much warmer than the outer frame, and so has a higher moisture content. In some double frame wall designs, builders install plywood bracing between the two frames at a few points.

7. Other varieties of double stud wall have been built. Whatever double wall technique is chosen, care should be taken to seal the air-vapour barrier properly at corners (see Figure 28). Windows, doors, pipes, vents, interior partitions, and other breaks also require sealing, as outlined in Worksheet N.

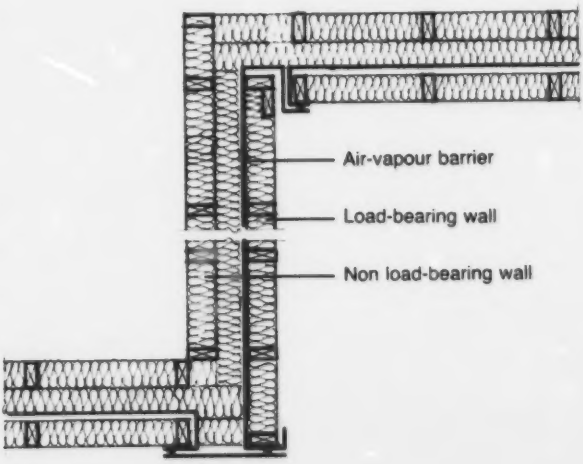

Figure 28. Corners in double wall construction

Worksheet N

Sealing Wall Air-Vapour Barrier at Obstructions

1. The partition wall frames are usually installed at the same time as the rest of the house frame. Later, when the air-vapour barrier is installed, its continuity is interrupted by the partition wall frame. This occurs most commonly at the top of partition walls and at the outside stud where it joins to the exterior wall. If the house has an unheated crawl space, the partition wall also interrupts the vapour barrier that must be laid across the floor.

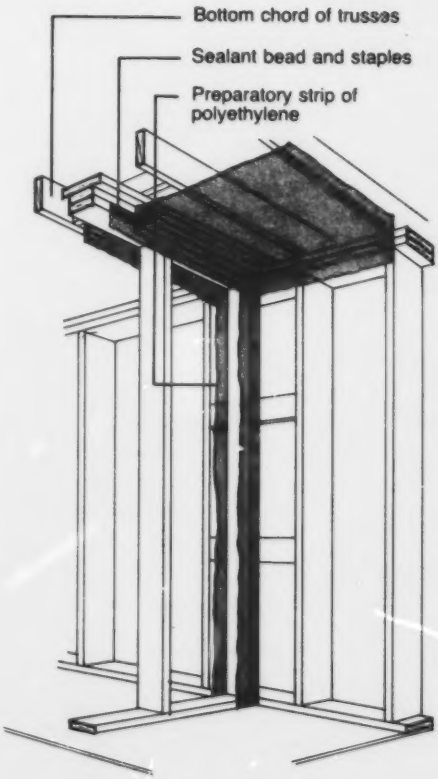

Figure 29. Air-vapour barrier detail where partition walls join exterior walls and ceilings

One solution is to provide a preparatory strip of polyethylene around the partition wall before it is installed. Figure 29 shows how this can be done in a single storey wood frame house. (Note that the preparatory strip passes between the two top plates.) Later, when the various ceiling and wall barriers are installed, they are sealed and joined (using the typical techniques) to the preparatory strip to give continuity around the partition wall.

Another technique is to apply the air-vapour barrier to the whole house envelope before the partition walls are installed. This has some advantages and some disadvantages. It is good practice if truss lift (see Chapter 6) is likely to be a problem.

2. If a wire must penetrate the air-vapour barrier (for instance, if the barrier is not located within the wall or where electrical service enters the house from outside), the wire should pass through a drilled hole in solid wood. The hole in the wood should be caulked.

3. If the air-vapour barrier is not inside the wall, electrical outlets can be installed using a commercial vapour barrier pan made of hard plastic. This pan is sealed to the barrier. Alternatively, baseboard electrical fixtures can be installed. More generally, it is worthwhile to limit the number of electrical fixtures on exterior walls, subject to the requirements of local codes.

4. Sealing the air-vapour barrier around windows is covered in Chapter 7, doors in Chapter 8, and pipes and vents in Chapter 9.

Chapter 6

Ceilings

Insulation techniques for ceilings are logical extensions of standard insulation practices and the energy-efficient air-vapour barrier techniques described in this book. Worksheet O describes the steps for flat ceilings while Worksheet P covers cathedral ceilings.

Worksheet O

Flat Ceilings

Refer to Figure 30.

1. Ceiling insulation may be either batt or loose-fill, and should provide RSI values equal to or greater than those indicated in Table 1. Batt insulation has better long-term stability, but it is not easy to fit snugly around obstructions. Air gaps may be left under the batt, creating airflow channels that might short-circuit the insulation effect.

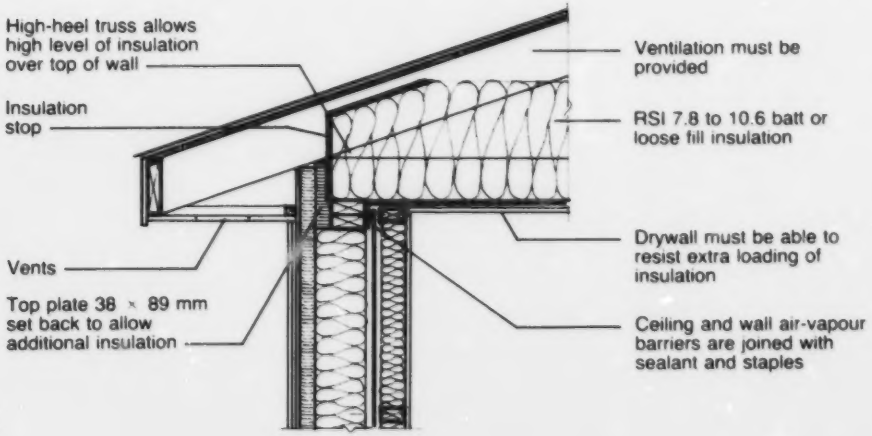
High-heel truss allows high level of insulation over top of wall
Insulation stop
Vents
Top plate 38 × 89 mm set back to allow additional insulation
Ventilation must be provided
RSI 7.8 to 10.6 batt or loose fill insulation
Drywall must be able to resist extra loading of insulation
Ceiling and wall air-vapour barriers are joined with sealant and staples

Figure 30. Ceiling insulation

Loose fill insulation overcomes this problem, but tends to compact after installation, giving a reduction in insulation levels. Loose fill is also prone to movement in high winds.

2. The air-vapour barrier is installed in the same position as in standard construction, but joints are sealed and stapled as indicated in Worksheet A. The same techniques are used to join the ceiling and wall air-vapour barriers, as indicated in Figure 30.

3. The extra thickness of insulation (up to 400 mm total) requires longer insulation stops and imposes extra loading on the ceiling structure. As a result, some houses have suffered from ceiling plasterboard sag shortly after construction. The degree of sag depends on the plasterboard thickness, the truss spacing, and the insulation loading — but the most critical factor is the level of humidity. If the trusses are spaced on 600 mm centres, a 15.9 mm (rather than a standard 12.7 mm) plasterboard should be used, as recommended by the manufacturer's association. Alternatively (and preferably) the ceiling can be strapped at right angles to the trusses, using 19 x 38 mm stock placed on 600 mm centres. This strapping will support the extra insulation load. In addition, it will provide a space between the drywall and the air-vapour barrier, which allows wiring to be installed without perforating the barrier.

4. Truss lift can be a problem in any house, but it may turn out to be a larger problem in houses with high levels of ceiling insulation. Truss lift is believed to occur when the upper and lower chords have different moisture contents, because of the difference in their operating temperatures. The differential moisture content causes deformation of the roof truss, resulting in an upward lift of the truss at the centre. This may produce cracking along the tops of partition walls. Solutions generally call for the interior finishing to be installed in such a way that truss uplifting does not cause any cracking of drywall or other similar damage.

The Technical Research Committee of HUDAC has prepared a bulletin on roof truss uplift that should be referred to by designers and builders.*

5. The outer perimeter of the ceiling is a major source of heat loss. To combat this the roof truss should be designed with either a raised heel or a steep slope, to allow a high level of insulation over the top of the wall.

6. The levels of attic ventilation required by the building code are somewhat arbitrary, and have persisted for many years because they seem to be working satisfactorily; that is to say, these levels of ventilation give adequate control of attic moisture in the majority of cases. However, in an energy-efficient house, with an airtight air-vapour barrier, the movement of water vapour into the attic space is much reduced and the need for attic ventilation is therefore not so great.

When air flows through an attic, it will induce air flow in the insulation and thereby reduce its insulating effect. The size of the effect will depend on the severity of the air flow. The implication of this is that unnecessary ventilation will reduce the effective insulation levels.

In the energy-efficient house of the future, it is possible that soffit ventilation will be reduced. For the present, it is recommended the EE houses follow standard attic ventilation practices. In areas subject to large amounts of blowing snow, care should be taken to prevent the snow from entering the attic space.

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* *Seasonal Uplift of Roof Trusses*. HUDAC Technical Bulletin No. 3. (Toronto: Housing and Urban Development Association of Canada, 1980.)

7. Where a hot flue passes through the air-vapour barrier, the main problem is to achieve good airtightness and good insulation without running the risk of flammability and high temperature deterioration of materials. Figure 31 shows how this can be achieved at ceiling level around a furnace flue.

Ceiling insulation is kept clear of the flue (to provide the required combusion clearance) by a metal cylinder centered around the chimney with the help of the blocking. Metal chimney firestops are insulated with a "low binder" mineral wool insulation: note that not all mineral wools are suitable for this application. The flue should be sealed to the firestops, but there is no good way of achieving this. Any sealant is soon cracked by the expansion movement of the flue. The best that can be done is to reduce the size of the gap with a non-flammable caulking material. Some builders use muffler cement.

Some of the problems associated with hot flues can be solved by the use of factory built chimneys. Each furnace type requires a different class of flue.

8. The seal around a vent stack has to allow for the stack expansion. The traditional technique, using packed oakum around the stack as shown in Figure 32, is satisfactory provided that the job is done properly (that is, the hole through the top plates is circular and about 15-25 mm larger than the stack).

9. Where possible, attic hatches should be installed on the attic gable or in an unheated garage. If the hatch is installed in the ceiling, it should be sealed and insulated as shown in Figure 33.

10. Kitchen and bathroom exhaust vents should not be installed through the ceiling (see Worksheet S).

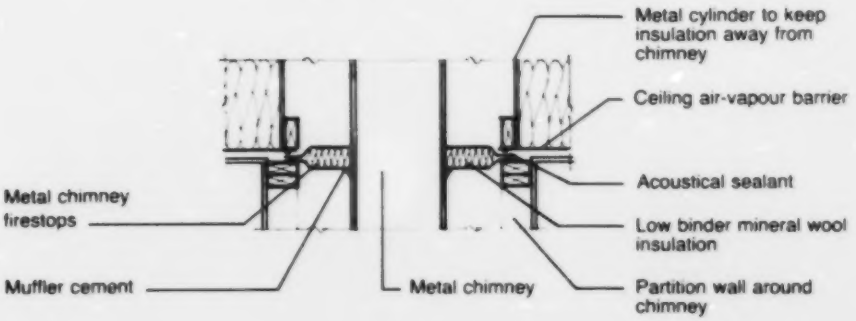

Figure 31. Sealing and insulating around a metal chimney

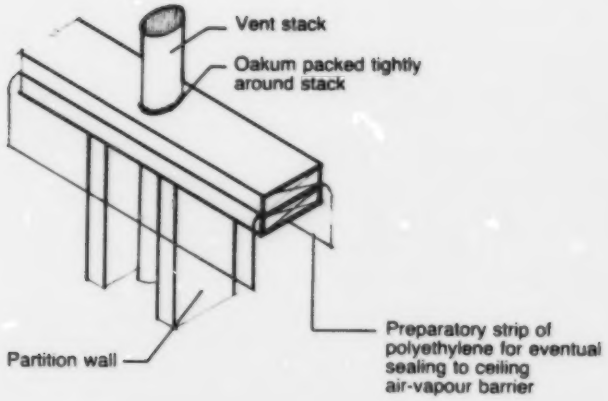
Vent stack
Oakum packed tightly around stack
Partition wall
Preparatory strip of polyethylene for eventual sealing to ceiling air-vapour barrier

Figure 32. Sealing a vent stack

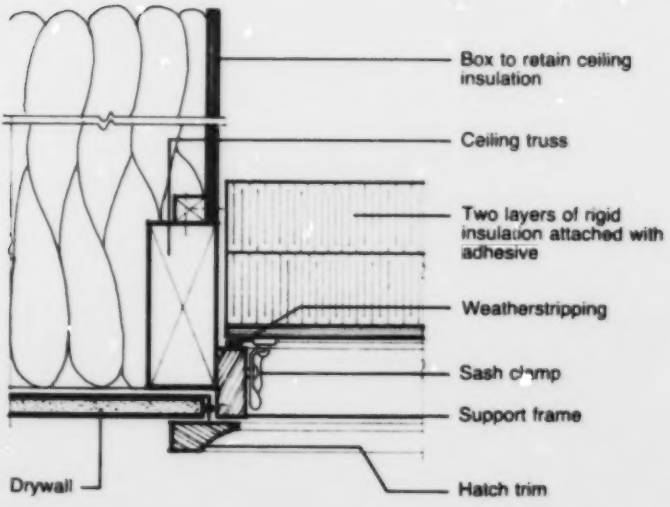

Figure 33. Attic hatch sealing and insulation

Cathedral Ceilings

A cathedral ceiling has similar requirements to a normal attic. It needs a good air-vapour barrier, insulation, and ventilation to remove any moisture that might accumulate.

Customarily, cathedral ceilings are built with 38 x 140 mm or 38 x 190 mm solid wood rafters. The depth is insufficient for the inclusion of a good level of insulation **and** a ventilation space. As a result, cathedral ceilings often have their cavities packed with insulation, and there is no provision for ventilation.

In the energy-efficient house, the cathedral ceiling should be designed to give ample insulation, and must tackle the problem of ventilation.

Worksheet P

Cathedral Ceilings

1. The most realistic way to achieve high insulation levels and ventilation in cathedral ceilings is through the use of specialized prefabricated trusses (sometimes referred to as trussed rafters). These trusses can be manufactured with a considerable depth. In addition, most have an open web construction that allows cross-ventilation between truss spaces, which is advantageous because it allows any escaping moisture to be dissipated over a wide area.

2. There are a variety of such trussed rafters, as illustrated in Figures 34 and 35. The I-beams are unlike the other three truss types in that each truss space is sealed from the others. As such, the I-beams require continuous ridge and soffit ventilation, as illustrated in Figure 36.

3. Whatever truss type is used, batt insulation with RSI values equal to or exceeding the levels cited in Table 1 should be used.

4. Air-vapour barrier detailing is similar to that for flat ceilings (Worksheet O).

Parallel chord trusses

Scissors truss

Figure 34. Truss types

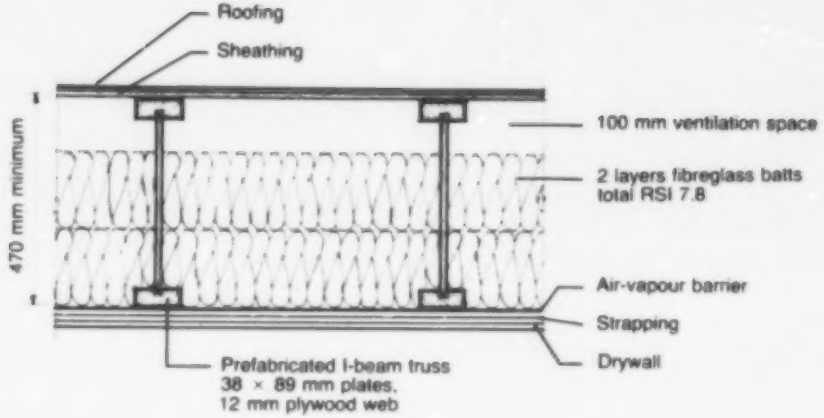

Figure 35. I-beam type truss

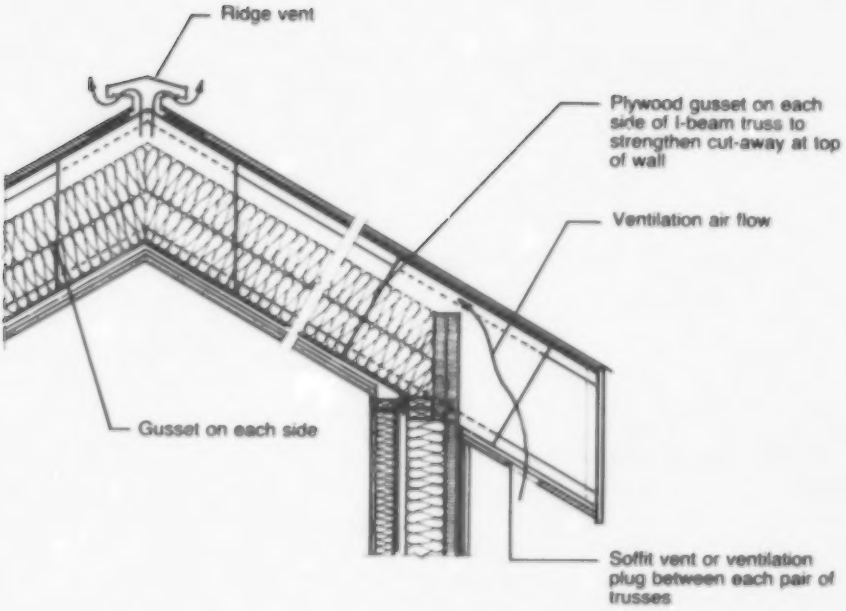

Figure 36. I-beam cathedral ceiling ventilation

Chapter 7

Windows

Windows generally provide insulation levels in the range RSI 0.25 to 0.50. In an energy-efficient house, with wall insulation levels in the range RSI 5.1 to 6.9, the window is the equivalent of a thermal hole-in-the-wall, and is a major weakness in energy-efficient design.

Windows lose heat in four distinct ways:

- transmission heat loss through the glass
- conductive heat loss through the window frame and glass
- infiltration heat loss around openable window sections
- infiltration heat loss where the air-vapour barrier is imperfectly sealed to the window frame.

Worksheet Q considers, in turn, ways to reduce each of these losses, and also considers ways to increase passive solar gain (which can turn windows into net heat producers rather than losers).

Worksheet Q

Windows

1. Transmission of Heat Loss Through Glass:

a. Better double-glazed windows have an air gap of 15.8 to 19.0 mm between the panes. The thermal resistance falls off when the air gap is above or below this range.

b. Better triple-glazed windows have two airgaps of 15.8-19.0 mm each. For such windows, the thermal insulation level is nearly double that of double glazing.

c. Fixed windows should probably be fitted with triple glazing. Operable windows cannot readily accommodate the thickness required by properly spaced triple glazing, and so can probably be fitted only with double glazing.

2. Conduction Loss Through the Window Frame:

a. Metal frames with thermal breaks, wood frames, and vinyl frames offer the best performance with respect to frame heat loss.

3. Infiltration Heat Loss Around Openable Parts:

a. In the energy-efficient house the window has to be judged both as a heat loser and as an integral part of the air- vapour barrier envelope. If the house has an airtight barrier, it does not make sense to use cheap windows with high levels of infiltration.

b. Most of the infiltration through the window unit proper occurs around the openable sections. To reduce this infiltration, the openable sections should be kept to a minimum acceptable size. The window should be selected for the quality of its seals, or on the basis of its specified infiltration performance. Hinged type windows are generally able to achieve a better seal than sliding types.

4. Infiltration Around Air-Vapour Barrier Joint:

a. In the energy-efficient house the air-vapour barrier is terminated in an airtight joint at the window frame. This joint can be achieved as shown in Figure 37. A strip of polyethylene is sealed (using standard EE techniques) to the window casing before it is inserted into the rough opening. Extra loose polyethylene should be left at each window corner so that it can later be folded (rather than cut) to meet the wall air-vapour barrier.

b. Once the window is in place, insulation (fibreglass or polyurethane foam) should be stuffed or blown into the gap between the rough opening and the window casing. The window and wall air-vapour barriers are then sealed

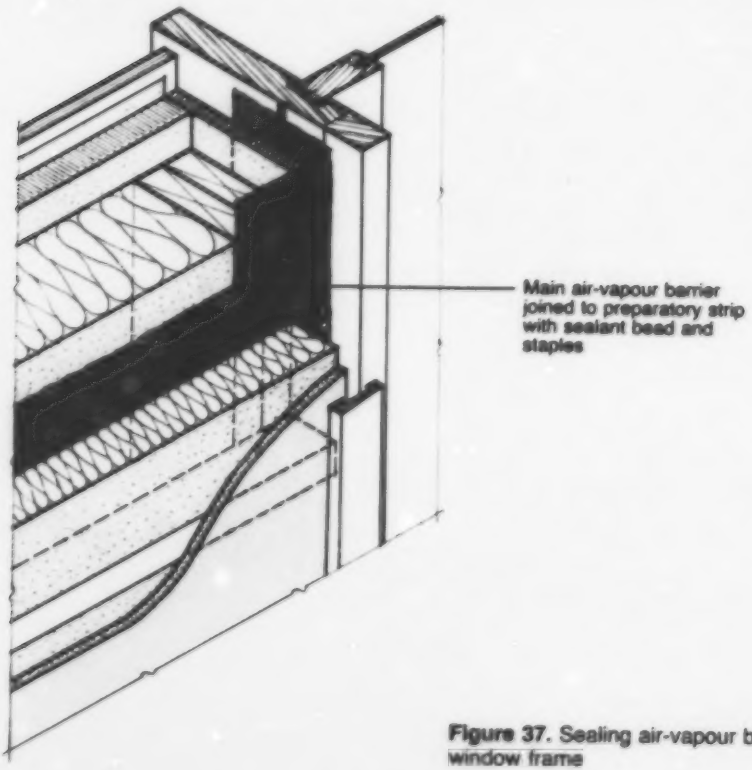

Figure 37. Sealing air-vapour barrier to window frame

together, following the procedures described in Worksheet A. Special attention should be applied to the sealing of the polyethylene folds at the window corner.

c. An alternative to the technique shown in Figure 37 is to seal the wall air-vapour barrier directly to the window frame. This is not a preferred approach, however, since it offers less protection against accidents during construction and against long-term movement of the house structure.

5. Passive Solar Design:

a. The principles of passive solar were discussed in Part I. In a good design, the house windows should be concentrated as far as possible on the south-facing wall, with minimum window area on all walls that have no direct sunlight in winter. The total south-facing window area should be sized at about 6 to 8 per cent of the heated floor area. This allows a level of solar gain that the house can handle, with not too much temperature elevation during the day and not too much cooling at night. The window area can be increased slightly (above 8 per cent of heated floor area) if the house has additional thermal storage.

b. With a good passive design, some change is required from the traditional interior layout of houses, to accommodate the uneven window distribution. Also, it may be beneficial to provide a continuously-operating air circulation system (such as low-speed fan circulating air via the usual heating system ducts). This system will distribute the solar gains around the house.

c. Overhangs that admit winter sun and exclude summer sun must be carefully sized (see Figure 5). The actual dimensions of the overhang will depend upon geographic location (which affects the angle of the sun) and the shape of the windows. The overhang should allow for full sun into the windows until February 1. Data on local sun angles is readily available, and the mathematical calculation required is straightforward.

Note: Considerable effort is being devoted to the development of movable insulation for windows. This insulation is removed during the day, to allow for passive solar gain, light, and so on. At the end of the day, it is replaced on the window, reducing the heavy nighttime heat loss through the glass.

Reasonably priced and effective movable insulation is proving to be a difficult goal to achieve.

Chapter 8

Doors

Doors lose heat in four ways:

- conduction heat loss through the door material
- conduction heat loss through the frame
- infiltration loss around the door
- infiltration between the door frame and the air-vapour barrier.

Worksheet R considers ways to reduce these losses in an EE house, without incurring undue cost.

Worksheet R

Doors

1. Conduction heat loss through the door is reduced most effectively by a thermal door, which has an RSI value of about 2.1, as compared to a wood door's RSI 0.3 to 0.4.

2. Infiltration loss around the door depends mainly on the quality of the seals and the care that is taken in installing them. In the case of both the thermal door and the wood door, a good self-adjusting seal with great flexibility and movement should be reasonably airtight. As a general rule, in the energy-efficient house, the door seals should be accorded as much importance as the door's thermal resistance.

3. Infiltration loss around the door frame is controlled, in the EE house, by sealing the wall air-vapour barrier to an air-vapour barrier strip wrapping the door frame. The technique is similar to that outlined for windows in Worksheet Q.

4. The addition of a storm door has only a minimal effect on the overall energy performance of a house. Therefore, the main purpose of the storm door, in the energy-efficient home, is to provide a screened ventilation opening in summer.

Chapter 9

Air Management: Indoor Ventilation

As was outlined in Part I, the airtightness of highly energy-efficient houses creates — directly or indirectly — three special air management needs:

- the need for ventilation to provide fresh indoor air
- the possible need for a separate supply of combustion and draft air
- the possible need for measures to maintain negative pressurization.

The provision of combustion and draft air and the maintenance of negative pressure are discussed in the next chapter; this chapter focusses on ventilation.

In conventional construction, fresh indoor air is provided by the many air leaks found throughout the house. However, in an energy-efficient house, natural air change would normally be reduced to such an extent that one complete change takes at least ten hours – too long to control humidity, odours, and pollutants. Such a house therefore needs additional ventilation to ensure that the indoor air is replaced at a minimum rate of one complete change every two to three hours.

Controlled ventilation can be supplied in various ways, some of which provide for heat recovery. Worksheet S outlines one approach.

Worksheet S

Ventilation

1. A basic EE ventilation system is illustrated in Figure 38. It involves the use of a ventilating device (in this case an air-to-air heat exchanger) that recovers heat from exhaust air by tempering incoming outside air. The rate of ventilation can be pre-programmed, controlled manually, and/or controlled by a humidistat (which activates the system when humidity levels rise above a set level).

2. The collector ducts draw warm stale air from one or more points in the house. If local codes and the heat exchanger's capabilities permit, these intakes can include bathroom and kitchen exhaust vents, if each is equipped with a backdraft damper to prevent inter-connection. These dampers become redundant when the device is meant for continuous operation. In addition or instead, the ducts can simply draw air from any nearby room(s) of the house, much as the cold air return of a furnace does. The size, length and path of the ducts should be chosen for minimum pressure drop.

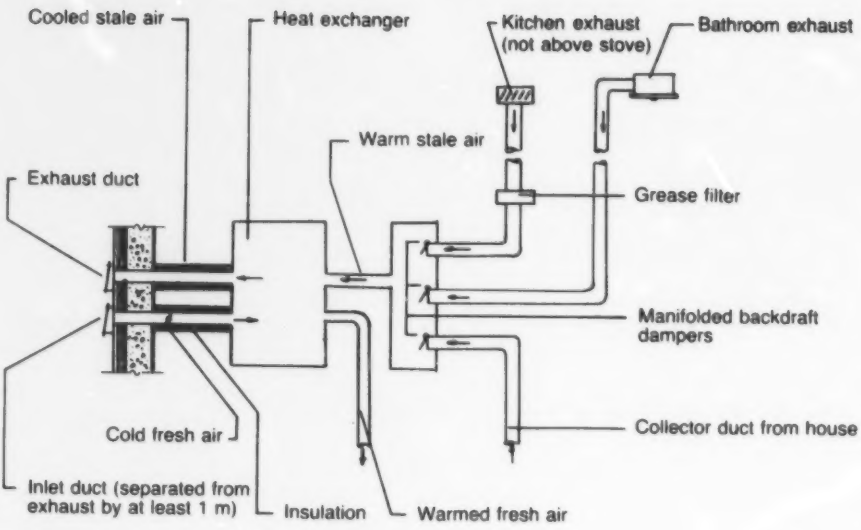

Figure 38. Ventilation system with heat exchanger

3. In principle, dryers could also be vented to the outside through the heat exchanger. However, the current state of domestic heat exchanger design does not generally allow for the flow and high temperatures associated with dryer venting. (Dryer venting inside the house is not recommended due to the moisture and the lint that would be released into the house.)

4. The fresh air duct carries tempered outside air into the house. It can discharge either directly into a room (perhaps creating a cool draft) or near a return air inlet of the heating system.

5. The exterior inlet and exhaust vents may be installed through joist headers or through the foundation. They should be positioned far enough apart to avoid cross flow, but close enough to ensure that both vents experience the same wind loading. It is recommended that the vents have a separation of at least 1 m and that they be installed on the same wall, well away from corners. The national code on natural gas burning appliances requires a clearance of at least 1 m between these vents and any gas connection.

6. The intake and exhaust ducts should both be insulated and the air-vapour barrier should be sealed around the ducts. Figure 39 shows a sealing technique for use when the basement wall is insulated on the inside.

Note: CSA has published detailed guidelines for the installation of ventilation systems.

7. In principle, a system similar to that shown in Figure 38 could be set up without a heat exchanger, as shown in Figure 40. If desired, the exchanger could readily be added at a later date.

8. Whether a heat exchanger is used or not, if bathroom and kitchen exhausts are not fed into the ventilation system they should be routed downward and out through the floor header, rather than through roof vents. This reduces convection heat losses. In the case of long duct runs, it may be necessary to use a larger duct diameter to reduce flow resistance.

9. Regardless of what type of ventilation system is installed, combustion cooking devices should be strongly discouraged in airtight houses, because of the toxicity of their combustion products. Extraction hoods are not generally an effective solution to this problem.

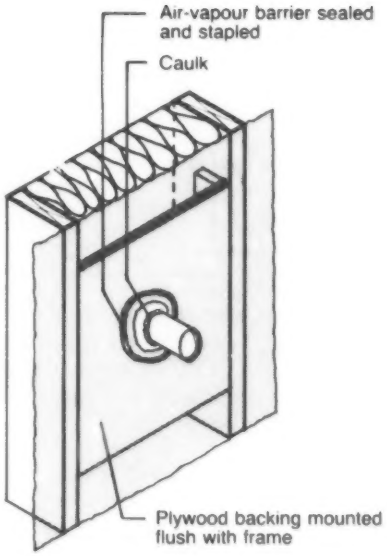

Figure 39. Sealing exhaust and inlet pipes

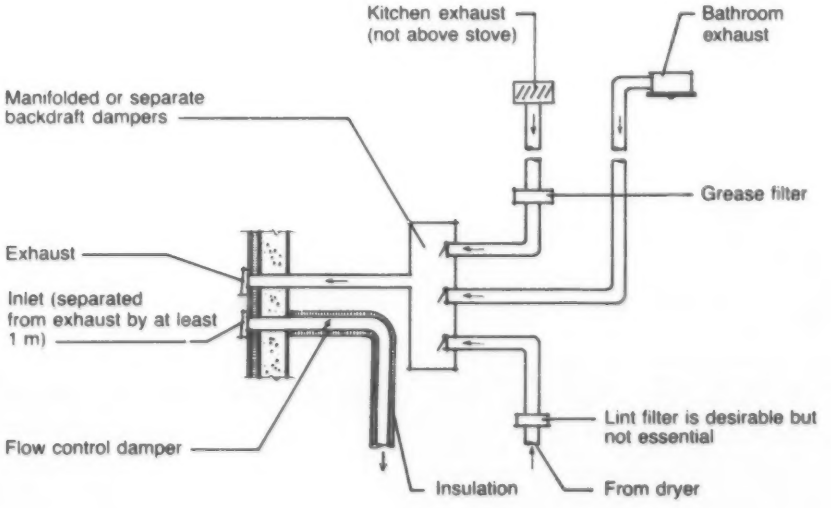

Figure 40. Ventilation system without heat exchanger

Chapter 10

Air Management: Other Aspects

Draft Air, Combustion Air, and Indoor Pressure

As was noted in Part I, furnaces and other fuel burning heating systems need a supply of combustion and draft air. As was also noted in Part I, it is most beneficial for house to exhibit a slightly negative indoor air pressure (relative to the outside), so as to reduce moisture movement into the walls.

For reasons that have been discussed, EE houses often require special measures to meet these needs. The measures are certainly necessary — but in most cases they are not overly complex.

The particular measures required are dependent upon the choice of heating system, since different systems have both different air needs and different impacts on indoor air pressures. In this respect, space and water-heating systems fall into three general categories:

1. Systems that draw no combustion or draft air from the house. For instance:
   - electric resistance heating
   - heat pumps with electric back-up
   - condensing gas heat pumps
   - solar heating
   - combustion systems outside the house
   - pulse combustion condensing gas furnace.

   For obvious reasons, such systems require no special supply of combustion or draft air. Worksheet T outlines the particular air management measures required to induce a negative pressure in houses heated by such systems.
2. Systems that draw combustion air from the house, but not draft air. For instance:
   - induced draft gas furnace
   - condensing gas furnace.

Worksheet U outlines the particular air management measures required by such systems.

3. Systems that draw both combustion and draft air from the house. For example:
   - conventional gas furnaces
   - conventional oil furnaces.

   Worksheet V outlines the particular air management measures required by such systems. Note, however, that such systems are not normally recommended for airtight houses. In fact they are incompatible with and inappropriate for these improved buildings which are constructed to high performance standards.

Woodstoves, fireplaces, and portable combustion heaters are discussed separately, at the end of this chapter.

Note that the air management measures outlined in Worksheets T, U, and V are **in addition** to the necessary ventilation measures outlined in Chapter 9.

Worksheet T

Air Management / Heating Systems Requiring No Draft or Combustion Air

1. Providing Negative Pressure:

a. In order to ensure that the house is under negative pressure (slight vacuum), an insulated 150 mm diameter duct with a controlled damper must be installed. This duct should preferably be located at the top of a stairway, or in an area into which other open circulation spaces converge. It should start at or near the ceiling and connect to a ridge vent with a 100 x 400 mm standard duct connector. Where the duct penetrates the air-vapour barrier, care should be taken to achieve an airtight seal.

b. When open, this duct will naturally act as a flue, discharging air from the inside of the house to the outside, thereby providing negative pressure in the house. However, the amount of discharge is limited by the rate of infiltration.

c. The damper should be controlled electrically by a humidistat. Use of a humidistat is preferable, since it will automatically open the damper when negative pressure is most needed (that is, when the humidity is high). Ideally the control should respond to pressure differences but such a device is not yet available. It is very likely that under many circumstances the damper will be open most of the time.

2. Other Comments:

a. The absence of combustion systems or their isolation from the house offers the highest standards of air quality and safety, since there are no combustion byproducts or they are entirely segregated from the air moving system of the house.

Worksheet U

Air Management / Heating Systems Requiring Combustion Air Only

1. Providing Combustion Air:

a. Because the air consumption of heating systems requiring only combustion air is low, and because they will still operate safely at negative pressures, it is less imperative but still necessary to provide a special air supply for them.

2. Providing Negative Pressure:

a. Although these furnaces do consume air from the house, their demand is not sufficiently large to assure negative pressurization of the house.

b. The house should therefore be provided with a duct and damper system, as described in Worksheet T.

3. Other Comments:

a. These furnaces generally have a high efficiency. Though their cost is substantially higher than that of conventional furnaces, the higher cost will be at least partially offset by the energy savings and perhaps by the fact that a flue is not required.

Worksheet V

Air Management / Heating Systems Requiring Combustion and Draft Air

1. Providing Combustion and Draft Air:

a. The air requirements of most conventional heating systems are large. In an airtight house, therefore, these systems definitely require a special outside air supply.

b. The simplest way to provide this is to put the furnace (and combustion water heaters) in a separate furnace room, with outside air ducted directly into the room (see Figure 41).

c. The duct should terminate in the vicinity of the furnace. The size of duct may be stipulated by building codes; if not, ensure that the size is suitable for the size of the furnace. It should be noted that some building codes prohibit the use of a damper in this duct. Where permitted, it is electrically controlled by the furnace cycling. Note that such control may be unwelcomed by the furnace manufacturer.

d. To maintain the airtightness of the main house, the furnace room must be isolated from it. This is achieved with a continuous and sealed air-vapour barrier plus good quality door seals. In addition, it must be realized that the cold air return and heat distribution ducts that pass through the furnace room are circulating air from the main house. These must be sealed from the furnace room.

e. The temperature in the furnace room should not be allowed to drop below about 10°C. If it does, excessive condensation or even freezing may occur in the flue(s). In addition, at colder temperatures furnace efficiency will tend to be lower and the furnace warrantee may become invalid.

f. The furnace room should therefore not be insulated from the house, but should be insulated on the exterior of the foundation wall.

g. Ventilation and heat recovery devices should not be located in the furnace room. They would only complicate the sealing of the room and interfere with the operation of each other.

h. A flue damper will help to minimize heat loss from the furnace room. However, these devices should only be used if there is no danger of the flue being over-cooled between furnace firing cycles. This criterion is important: as in the case of an excessively cold furnace room, condensation and even icing may take place in a flue that is too cold. Generally, flue dampers may be safely used in a flue which is insulated or at least not overly exposed to the elements. Flues or chimneys which are located on exterior walls, on the other hand, may be quite unsuitable, since they are prone to rapid cooling.

i. A better method of controlling the loss through the flue is by introducing a motorized damper on the intake duct. Because the furnace room is airtight, the flow of air up the flue will be restricted if there is no compensating flow through the intake. In addition, controlling the intake also lessens the probability of very low temperatures in the furnace room and, by linking the damper operation to the furnace, good combustion and no spillage are assured. However this design option is yet to be matched with compatible products and, in some localities, may not be permitted.

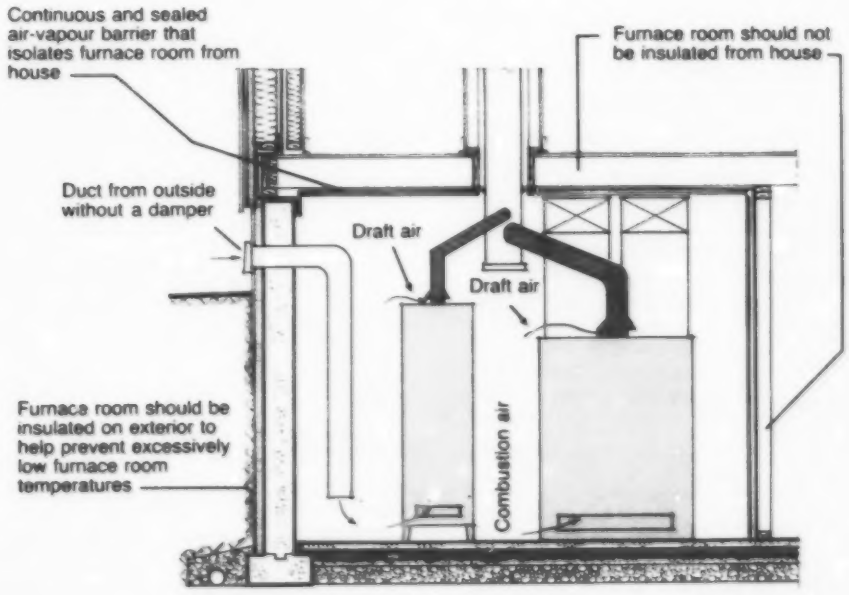
Continuous and sealed air-vapour barrier that isolates furnace room from house
Furnace room should not be insulated from house
Duct from outside without a damper
Draft air
Draft air
Furnace room should be insulated on exterior to help prevent excessively low furnace room temperatures
Combustion air

Figure 41. The furnace room

j. Finally, it is important to ensure a good match between the capacity of the furnace and the heat load. If the furnace is over-sized, the duct to the outside will also be unnecessarily large. This could lead to over-cooling of the furnace room. In addition, the long periods between furnace operation that can occur in EE housing may allow excessive cooling of the flue or chimney.

2. Providing Negative Pressure:

Systems requiring combustion and draft air generally induce a negative pressure in the house.

Fireplaces and Woodstoves

Fireplaces and non-airtight woodstoves are not generally recommended for EE houses. If a fireplace is installed, it must have its own air supply. Even with such a supply, the heat losses up the chimney will be significant.

Woodstoves used as a major heat source should be airtight models connected directly to an intake pipe supplying outside air. The duct should be insulated to prevent condensation on its surface, and should be sealed where it breaks the air-vapour barrier.

Airtight woodstoves to be used on an occasional basis only may not require a separate outside air supply, if the measures designed to produce a negative indoor air pressure are inoperable while the stove is in use. Even for such occasional use, however, it is better practice to install an outside air supply.

Portable Combustion Heaters

There is a growing market for portable combustion heaters, particularly the kerosene-fueled variety. Being portable, they can have neither a combustion air supply system nor a flue system. The rate of combustion may not be high enough to create an air demand problem in an airtight house, but the combustion process gives off a large amount of water vapour. This may raise the humidity level to the point where condensation becomes a problem. Increased concentrations of carbon dioxide and decreased concentrations of oxygen will also result. Such heaters should certainly be discouraged in airtight houses.

Conclusion

The design and construction of energy-efficient houses involves some departure from standard building practices. This book has introduced some of the major technical innovations associated with EE housing. Newer ideas, approaches, and techniques will be developed over time, but the field has already progressed rapidly.

Good EE housing involves more than just attention to the air-vapour barrier and the construction details outlined in this book. Energy efficiency implies attention to other issues as well. For instance:

A large house requires more space heat than a smaller house. Modest house size and thoughtful, efficient use of space are therefore energy conserving measures. Small is better.

House shape influences energy efficiency. The total area of exterior wall and ceiling can vary tremendously for a given quantity of useable floor space. The closer a house's heated interior comes to a cube shape, the more energy efficient it will be.

The choice of heating system affects the energy demands of the house: an oversized furnace may waste some of the energy so carefully saved by the various EE measures.

Site design can influence energy efficiency. Hedges, trees, berms, and outbuildings, for instance, can be positioned to break prevailing winter winds.

Conscientious construction practices, thoughtful design, careful inspection, and an interested homebuying public are essential requirements for a vigorous EE housing industry. There is no reason why these requirements cannot be met. It seems inevitable that energy-efficient houses will take a steadily growing share of the Canadian housing market.

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